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Long-Term Effects of Slow-Rate Land Application of Municipal Wastewater A Critical Summary

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McLean, VA

Prepared for

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EPA 600/7-81-152
September 1981

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LONG-TERM EFFECTS OF SLOW-RATE LAND APPLICATION OF MUNICIPAL WASTEWATER

A CRITICAL SUMMARY

by

Alex Hershaft
Bruce Truett

Contract No. EPA 61-01-5051
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16. ABSTRACT

Long-term effects of applying partially treated municipal wastewater to croplands were examined at six locations in the western U.S. All locations had received wastewater for at least 10 years. The effects on soil, groundwater and crop tissues were measured and compared with measurements made at nearby control sites where crops were irrigated with water from wells or other conventional sources.

Data for some 50 parameters measured at the six sites are summarized in this report. The data indicate that the soil and plants effectively reduce the concentration of most pollutants in the wastewater. There is a buildup of certain pollutants in the soil, however. Others pass through the soil to the groundwater, although usually in concentrations that do not exceed Federal drinking water supply standards. An important exception is the concentration of nitrate-nitrogen, which exceeded the drinking water standard at three locations. At no site was there any reported evidence of adverse health effects on farm workers or nearby residents. Measured values of hydraulic loading fell within the allowable limits estimated by the Process Design Manual for Land Treatment of Municipal Wastewater procedure, but measured values of percolate nitrogen concentration did not correspond closely to estimated allowable limits. Recommendations are made concerning possible modifications to the Design Manual estimating procedures.

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ABSTRACT

Long-term effects of applying partially treated municipal wastewater to croplands were examined at six locations in the western United States. All locations had received wastewater for at least 10 years. The effects on soil, groundwater, and crop tissues were measured and compared with measurements made at nearby control sites where crops were irrigated with water from wells or other conventional sources.

Data for some 50 parameters measured at the six project locations are summarized in this report. These were selected from the much larger volume of data presented in the project report for each location. Data summarized here indicate that the soil and plants effectively reduce the concentration of most pollutants in the wastewater. Some of the project reports indicate that the land treatment sites appear capable of performing this function for several additional decades. There is, however, a buildup of certain pollutants in the soil. Others pass through the soil to the groundwater, although usually in concentrations that do not exceed Federal standards for drinking water supply. An important exception is the concentration of nitrate-nitrogen, which exceeded the drinking water standard at three project locations. At none of the projects was there any reported evidence of adverse health effects on farm workers or nearby residents.

Procedures are given in the Process Design Manual for Land Treatment of Municipal Wastewaters for evaluating two limiting criteria for the design of slow-rate systems: hydraulic loading, and concentration of nitrogen in the leachate. These procedures were retrospectively applied to the designs of the six project locations addressed in this report. The results were compared with values measured at the project locations. Measured values of hydraulic loading fell within the allowable limits estimated by the Design Manual procedure, but measured values of percolate nitrogen concentration did not correspond closely to estimated allowable limits. Recommendations are made concerning possible modifications to the Design Manual estimating procedures.

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SECTION 1

INTRODUCTION

During 1976-1978, six field research projects were undertaken to investigate the long-term effects of applying effluent from municipal wastewater treatment plants to land used for agricultural purposes. The projects were located in six geographically diverse areas in the western United States. The effects on groundwater and leachate, soil, and vegetation were measured and compared with similar measurements at nearby control sites where conventional irrigation water was used.

This report summarizes results from the six field projects and presents conclusions based on these results. The present section outlines the background of this series of investigations. The six projects are described and their results presented in subsequent sections.

BACKGROUND

Disposal of domestic or municipal wastewater by application to the land was widely practiced in Europe and the United States during the 1800s for purposes of irrigation, as a means of utilizing the plant nutrient content of the wastewater, and as a means of reducing the amount of pollutants discharged to rivers and other surface waters. During the first half of the twentieth century, many of the land application systems were replaced by waste treatment plants employing mechanical, chemical, and biological processes. This trend was due in part to the diminishing supply of land available for wastewater treatment near population centers. The treated effluent from such plants has generally been discharged to rivers or other surface waters. In some instances, particularly in the western states, the effluent has been used for irrigation and groundwater recharge.

As late as the mid-1970s, land application of treatment plant effluent was done primarily for irrigating crops. The land application systems were

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designed to increase crop production rather than to remove pollutants from the effluent. Their effectiveness for pollutant removal has been widely recognized, however, and the use of land application as a step in total wastewater treatment systems became the subject of substantial research efforts by the U.S. Environmental Protection Agency (EPA) and other agencies. This led to the consideration of land application as a wastewater treatment process, to be evaluated as a supplement, or possibly an alternative, to other more conventional processes.

The number of wastewater treatment systems that employ land application of effluent has increased over the past 40 years from about 300 facilities serving an aggregate population of 0.9 million in 1940, to 940 systems serving an estimated 9 million in 1978.* This is still only a small fraction of the total number of municipal wastewater treatment facilities, estimated at approximately 22,700 in 1979. [1, 15, and 16].**

The growth of land treatment of municipal wastewater has been encouraged by Federal environmental legislation and policies during the 1970s. Regulations developed pursuant to the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) require that land treatment be considered, together with other alternatives, for federally funded municipal wastewater treatment projects. Continued emphasis was placed on the land treatment alternative by the Water Pollution Control Act Amendments of 1977. There was widespread interest in the land treatment provision of the regulations related to these two Acts, raising questions as to what criteria would be used to evaluate land treatment systems and compare them with conventional systems. In response to these questions, the U.S. Environmental Protection Agency, in cooperation with the U.S. Department of Agriculture and the U.S. Army Corps of Engineers, issued the Process Design Manual for Land Treatment of Municipal Wastewater in 1977 [1](hereinafter referred to as the Design Manual).

There has been a continuing concern about the environmental and public health impacts of land treatment of municipal wastewater, especially where

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* A larger number of land application systems (about 3,000) in use at this time period is given in Reference 18. This larger figure includes not only municipal systems, but smaller institutional and industrial systems, some of which are privately owned and operated.

** Numbers in square brackets denote the references listed in Section 10.

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the practice extends over a period of several decades. Potential problems underlying this concern are:

- Heavy metals and other toxic substances in the wastewater may be accumulated in the soil and vegetation, reducing crop yield and introducing these substances into the food chain.
- Heavy metals and other toxic substances in the wastewater may contaminate groundwater and surface water. Dissolved substances contained in the wastewater or leached from the soil may degrade the quality of surface water or groundwater used for irrigation or drinking water supply.
- Pathogens, including bacteria, viruses, fungi, protozoa, and nematodes in partially treated wastewater, may be dispersed as an aerosol by spray irrigation and inhaled, or may be deposited on crops and ingested by livestock or humans.

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In the early 1970s, EPA initiated a program of research, development, and demonstration that addressed principally the technical aspects of land treatment and offered the prospect of producing the sound information base needed for a better understanding of land treatment. In the mid-1970s, additional emphasis was placed on the health and ecological aspects of land treatment, addressing the concerns identified above. Projects within this overall program ranged from detailed studies of biochemical processes in crops to technical and economic studies of large-scale farming operations.

These projects included investigations of the effects of long-term application of treated municipal wastewater on the land and groundwater. The studies examined 10 land application systems that had been in operation for at least 10 years. While the studies cover only a short interval (12 to 18 months) in the total period of wastewater application at each site, the resulting data permit inferences to be drawn relative to the long-term effects of this practice. In addition, the data are expected to be useful in the evaluation of design criteria in the Design Manual. Six of the 10 studies examined slow-rate systems, where vegetation plays a critical rôle in the absorption of water and nutrients. The other four dealt with rapid infiltration systems, which rely principally on physical and chemical action of the soil to purify the applied wastewater.

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The results of the six slow-rate systems studies are summarized in this report. A parallel summary, prepared by the EPA staff at the Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma, covers the four rapid infiltration land treatment systems [2].

Locations of the slow-rate land treatment projects span a broad range of climatic conditions, soils, and topographic and hydrogeological configurations. All six of the land treatment systems investigated had received municipal wastewater for at least 10 years and one for more than 30 years. The projects were located in the vicinity of:

Camarillo, California
Dickinson, North Dakota
Mesa, Arizona
Roswell, New Mexico
San Angelo, Texas
Tooele, Utah

Criteria used in the selection of these project locations are summarized in Section 4.

PURPOSE, SCOPE, AND ORGANIZATION OF THIS REPORT

The purpose of this study is to summarize the results of the six slow-rate land treatment studies. The individual project reports contain all collected data and are quite voluminous. The summary presented in this report is intended for the reader interested in the principal findings and conclusions of the six studies. Readers who have need for the complete details should refer to the individual project reports [3 - 8].

The scope of this report may be delineated in terms of the project locations and sites, the pollutants or other parameters of interest, and the media in which the pollutants occur. Each project included a test site where crops were grown and where treated municipal wastewater was applied to the cultivated area, and (with the exception of San Angelo) a control site where crops were irrigated with water from a nearby river, an aquifer, or a municipal water supply.

The three principal media involved in slow-rate land treatment are water, soil, and vegetation. Approximately 50 pollutants or other parameters were measured in these media. The pollutants were categorized as nutrients, organics, solids, heavy metals, alkali and alkaline earth metals, nonmetals, and bacteriological indicators of pathogenic organisms. At the test and control sites, measurements were made on the applied water, the soil, the groundwater or leachate, and various parts of the crop plants. Some of the individual project reports also discussed the effects of wastewater application on mechanical properties of soils, and the financial gains to be realized from utilizing the nutrients contained in the wastewater.

Conclusions drawn from the comparison and analysis of the six projects are presented in Section 2 and recommendations made on the basis of this analysis are given in Section 3. These conclusions and recommendations are based ultimately on field measurements, and are subject to the constraints and limitations of such measurements as outlined in Section 5. The design and operation of the six land treatment systems are described in Section 4 in terms of the physical layout, geological and soil profiles, hydrological flow patterns, climatic profile, land uses, types of vegetation grown, and pretreatment and application rate of the wastewater. The sampling methods in the different media and the analytical procedures for the various pollutants are specified in Section 5 to the extent permitted by the source reports. Concentrations of pollutants in all media are reported in Section 6 for each project location. The performance of each of the six systems is reported and analyzed, first for each location (in Section 7), and then for each category of pollutants (Section 8). Finally, in Section 9, measured values of two system performance parameters -- hydraulic loading and nitrogen concentration in the percolate -- are compared to the allowable values as estimated by procedures in the Design Manual.

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SECTION 2

CONCLUSIONS

The following conclusions were drawn from data in the project reports summarized in this report.

- All six slow-rate land treatment systems generally reduced the levels of major pollutants in the applied wastewater below those typically found in effluent from secondary treatment.
- None of the six investigations reported any significant threat to the public health through airborne dispersion of pathogens or contamination of drinking water supplies or vegetation.
- Large amounts of nitrogen and phosphorus were taken up by the crops, but nitrate levels in the leachate increased with depth and occasionally exceeded the EPA standard for drinking water supply.
- The organic matter content, as indicated by BOD and COD levels, was effectively attenuated by the soil, although precise measurement of the attenuation was not always possible when the amount of applied wastewater varied rapidly with time.
- Since suspended solids were filtered out within the first few centimeters of the soil bed, their concentration in the leachate was not measured.
- Concentrations of both total dissolved solids and individual dissolved solids generally increased with depth. Some deposits in the soil were leached out by the applied water.
- None of the six facilities received much industrial wastewater with its typically high concentration of heavy metals. The small concentrations of heavy metals that were found in the soil did not change appreciably with depth. Heavy metal levels in vegetation were within normal ranges, and levels in groundwater were generally within the limits set by drinking water standards.

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- Water-borne pathogen levels, as indicated by measurements of fecal coliform bacteria, protozoa, and nematodes, appear to have been reduced below limits of detection by passage through the soil; some indicators of pathogenic organisms detected on vegetation were attributed to droppings by grazing animals.

- All six test sites investigated would have met the Design Manual's land requirement criteria based on hydraulic conductivity of the soil.

- Three of the six test sites would not have met the Design Manual's land requirement criteria based on nitrogen content in the percolate.

- On the basis of experience during 10 or more years of wastewater application at each of the six sites investigated, the effective life of land treatment systems is estimated to be several decades.

- The economic benefits of wastewater application extend beyond the lower cost of the water and include, in some cases, higher crop yields than at sites where conventional irrigation water was used. One project (Camarillo) reported a 12 percent higher yield at the test site.

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SECTION 3

RECOMMENDATIONS

- Slow-rate land treatment of municipal wastewater is demonstrated to be an effective means of reducing the concentration of most categories of pollutants. On the basis of the results of the six studies examined here, this method of wastewater treatment is recommended for consideration as a technically and economically viable supplement to conventional treatment processes and as an alternative to certain of the processing steps typically included in a treatment plant that discharges its effluent to surface waters.

- Although levels of many pathogens (fecal coliform, protozoa, and nematodes) were reduced below limits of detection by soil treatment, the degree of reduction of viruses is not clearly established. Information on viruses in the source reports suggests that further investigations be undertaken to obtain a better understanding of the prevalance and transport of viruses under various conditions of land treatment of wastewater. However, the subject of viruses was not the primary emphasis in the source documents, and in most cases was not addressed in great depth. It is therefore recommended that the need for additional studies of viral prevalance and transport be reviewed in the light of more recent investigations on these subjects (as reported in Reference 17, for example).

- The Design Manual procedure for estimating land requirements for slow-rate wastewater treatment systems should be reviewed for adequacy. In particular, the following modifications should be considered for any future edition of the Design Manual:

  -- The procedure for estimating maximum allowable application rates on the basis of the hydraulic conductivity of the most restrictive layer should be more thoroughly discussed.

  -- The procedure for estimating percolate nitrogen concentration could easily be modified to account for sources of nitrogen other than the applied wastewater (for example, fertilizer or animal droppings). Also, the discussion should point

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out that the procedure is based on the assumption of equilibrium (or steady-state) conditions, whereas conditions in the field may be highly dynamic during a short-term period of measurement.

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SECTION 4

SYSTEM DESIGN AND OPERATION

This section describes the design and operation of the six slow-rate land treatment projects. Following a brief delineation of the general design of a slow-rate treatment system, the site characteristics and operating parameters of the projects are presented in tabular form. Particular characteristics of the individual projects are then discussed in turn.

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GENERAL DESIGN OF SLOW-RATE LAND TREATMENT SYSTEMS

The general design of a slow-rate land treatment system is shown in Figure 1. While this design does not correspond specifically to any one of the six study projects, it represents all of the components normally found in a slow-rate treatment system. However, all of the components shown in Figure 1 are not required for slow-rate land treatment and are not included in every treatment system studied.

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The figure shows a control site as found in five of the six projects. The effluent from the primary or secondary treatment plant is transferred to one or more facultative lagoons where it undergoes additional oxidation and settling. Effluent from the lagoon(s) is transported to a holding pond, then to the test site where it is applied to the land by any of several methods. A nearby control site with characteristics similar to the test site is irrigated by water from a conventional source such as a well or a river. One or more principal crops are grown on the major portion of the area at both the test and control sites. Some of the projects also have experimental garden plots where a variety of crops are grown.

In the six projects described here, samples of applied water, leachate, groundwater, soil, and crops were collected at the test and control sites and analyzed for parameters of interest. Crop yields were reported for three of the projects.

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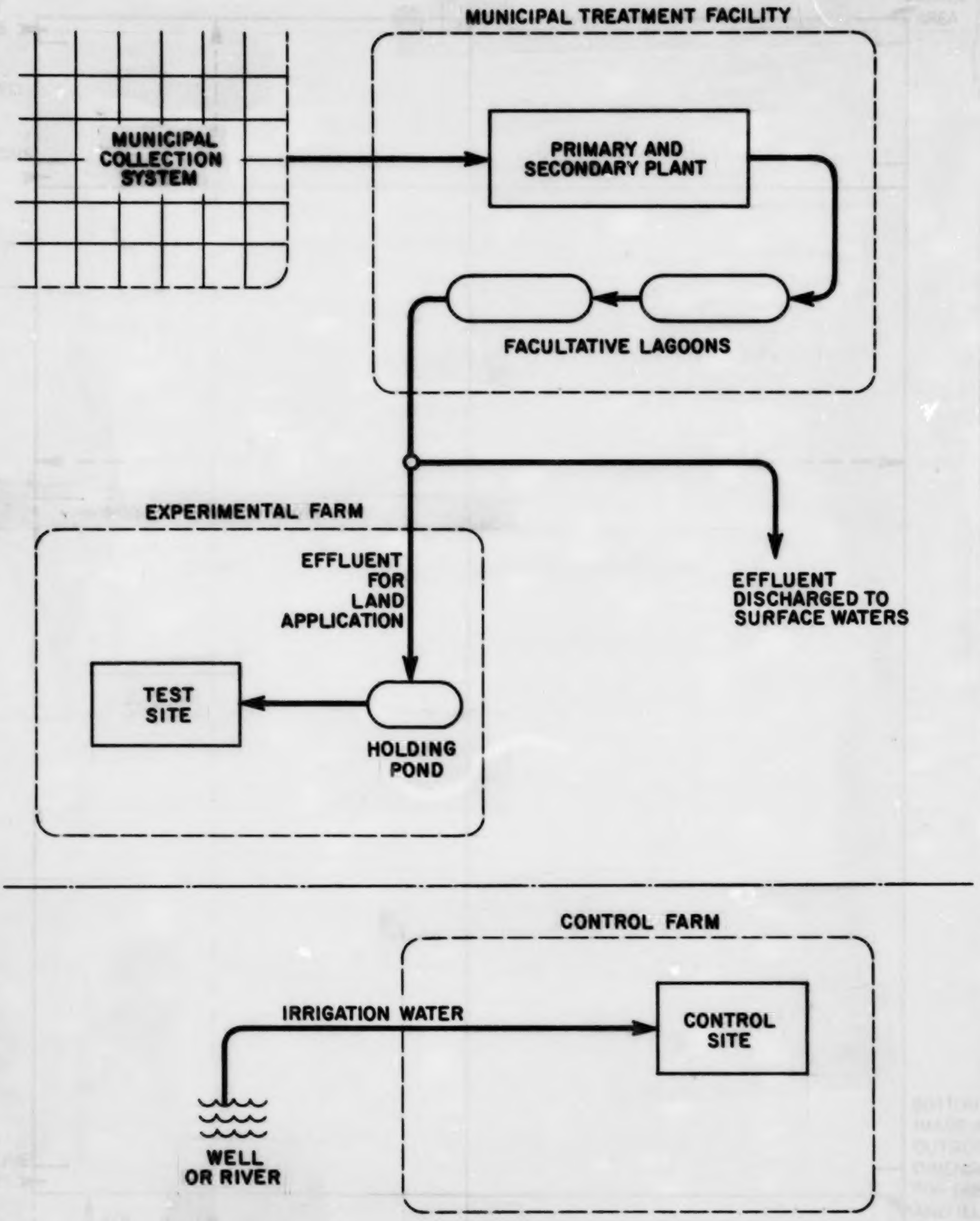
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PRIMARY AND SECONDARY PLANT
FACULTATIVE LAGOONS
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TEST SITE
HOLDING POND
CONTROL FARM
IRRIGATION WATER
CONTROL SITE
WELL OR RIVER

FIGURE 1 SCHEMATIC OF GENERAL PROJECT DESIGN

SITE CHARACTERISTICS AND OPERATIONS

The six projects are located in western states and all but one are in arid or semiarid climates.

Specific test sites for each project were selected after examination and evaluation of several alternatives in each of six geographic regions specified by EPA. Criteria for selection of the test sites included the following:

- The site had been irrigated with effluent for at least 10 years, and historical records were available for that period.
- The applied wastewater should be an effluent from either primary or secondary treatment facilities.
- Flow rates should be at least 4.38 liters/second (l/s) [0.1 million gallons/day (mgd)].
- Crops should be representative of common usage.
- A "good control site" should be available within a reasonable distance and have the same general type of soil and hydrogeological conditions.

A more complete listing of site selection criteria appears in Appendix A.

General characteristics of the area where each project is located are summarized in Table 1. Characteristics of the test and control sites, together with key operating conditions of the land application systems, are given in Table 2.

The following subsections discuss characteristics of each project which differ from the general system design shown in Figure 1. Design and operating features peculiar to each site are identified here.

Camarillo, California

The design of the Camarillo project follows the general system design (outlined above) in most respects. It differs from the other five projects in that the wastewater treatment facility employs partial tertiary treatment (fine polishing pond) and produces an effluent of exceptionally high quality. The effluent is piped from the treatment plant to a reservoir at the test site. From there it is applied to the test site by furrow flooding.

TABLE 1 GENERAL CHARACTERISTICS OF PROJECT AREA

Location	Topography	Elevation	Climate	Typical Temperatures (monthly averages) January	Typical Temperatures (monthly averages) Jul-Aug	Annual Precipitation	Wastewater Treatment Plant: Population Served	Wastewater Treatment Plant: Average Flow	Wastewater Treatment Plant: Industrial Flow	Wastewater Treatment Plant: Treatment Level	Depth to Groundwater	Predominant Soil Textural Classes
		m (ft)		°C (°F)	°C (°F)	cm (in)		m^3/day (mgd)	%		m (ft)	
Camarillo,	Gently sloping valley, hills nearby	49 (160)	Semi-arid	11 (52)	20 (68)	30 (12) (minimum)	a	8,500 (2.2)	10%	Secondary and partial tertiary (Activated sludge, clarification, polishing pond)	a	Mocho loam (~25% clay)
Dickinson, North Dakota	Rolling upland prairie	732 (2400)	Semi-arid	-13 (8)	21 (70)	38 (15)	13,400	37,800 (10)	b	Secondary (Trickling filters, lagoons with aerators, sludge digestion)	2 to 5 (6 to 15)	Fine sandy loam
Mesa, Arizona	Sloping river basin, mountains nearby	380 (1240)	Arid	10 (50)	30 (86)	18 (7)	a	17,300 (4.6)	b	Secondary (Trickling filter, settling, holding ponds)	30 to 153 (100 to 500)	Gravelly sand, sandy loam
Roswell, New Mexico	Gently sloping floodplains	1100 (3600)	Semi-arid	4 (40)	27 (80)	30 (12)	43,000	15,000 (4)	b	Secondary (Trickling filter, oxidation ditch, settling)	2 to 3 (6 to 9)	Silty clay loam
San Angelo, Texas	Gently sloping floodplains; hills nearby	550 (1800)	Semi-arid to Subhumid	7 (45)	24 (75)	53 (21)	67,000	21,000 (5.5)	7%	Primary (Screening, sedimentation, skimming, sludge digestion)	1.2 - 3.7 (4 - 121)	Gravel, sand, silty clay, conglomerate
Tooele, Utah	Mountains to the southwest; land slopes gently to arid basin	1470 (4820)	Semi-arid	-2 (29)	24 (75)	43 (17)	3,800	3,800 (1.0)	b	Secondary (Trickling filter, sedimentation, sludge digestion)	More than 33 (107)	Silt, silty clay, gravelly silt

a. Information not reported

b. Data not reported, but industrial flow assumed to be low in view of project location.

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TABLE 2 TEST AND CONTROL SITE CHARACTERISTICS AND OPERATING DATA

Location	Area[b]				Length of Effluent Application (Test Site)	Source of Applied Water		Method of Application		Rate of Application				Crops Grown		Leachate measured in:	
	Test		Control			Test[h]	Control	Test	Control	Test				Test	Control	Test	Control
	ha	(ac)	ha	(ac)	years					cm/yr	(in/yr)	cm/yr	(in/yr)				
Camarillo, California	16	(40)	19.6	(48)	10	Secondary & partial tertiary treatment	City water supply; on-site deep well	Furrow flooding	Furrow flooding; sprinklers	160[g]	(63)[g]	153	(60)	Tomato, Broccoli	Tomato, Broccoli, Spinach	Ground-water	Ground-water
Dickinson, North Carolina	5.7	(14)	4.5[c]	(11)[c]	15	Secondary treatment plant	River	Border strip flooding	Border strip flooding	80	(31)	140	(55)	Brome grass pasture	Brome grass pasture	Ground-water	Ground-water
Mesa, Airzona	44.5	(110)	12.6	(31)	14	Secondary treatment plant	River	Furrow flooding	Furrow flooding	502	(198)	165[d]	(65)	Barley, Sorghum, Corn	Sudan grass, Cotton	Groundwater and seepage to river bed	Ground-water
Roswell, New Mexico	6.5	(16)	16	(40)	30	Secondary treatment plant	Artesian well	Ridge & furrow flooding	Flooding[e]	81	(32)	81	(32)	Corn	Corn	Groundwater	Groundwater
San Angelo, Texas	259	(640)	No single control site; (see text)		18	Primary treatment plant	[a]	Border strip flooding	a	264	(104)	a		Grasses, Sorghum, Oats	a	Seepage creeks; river	Groundwater water or seepage creeks
Tooele, Utah	14	(36)	9	(22)	10	Secondary treatment plant	Reservoir	Flooding, sprinkldr	Sprinkler	48[f]	(19)	41	(16)	Pasture grasses, Alfalfa, Garden crops	Alfalfa	Unsaturated zone	Unsaturated zone

---

a. No control site at San Angelo - See text.
b. Refers to area investigated in the project, not necessarily total irrigated area of farm.
c. Estimated from site layout (area not stated in site description)
d. Effective rate, not total
e. Method of flooding not specified.
f. This rate was an average for the 10.5 ha (26 ac) sprinkler-irrigated portion; average for the 1.7 ha (4.2 ac) flood-irrigation-portion was 61 cm/yr (24 in/yr).
g. Total water applied; includes some loss by surface runoff.
h. See Table 1 for treatment processes.

a-1
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The control site at Camarillo is the only site in this series of investigations that uses water from a municipal supply system for irrigation. This source is supplemented by an on-site well [3].

Dickinson, North Dakota

The municipal treatment system at Dickinson consists of a trickling filter, sludge digester, and chlorinator followed by two lagoons with floating aerators. A third lagoon was under construction during the project period. Effluent for the test site was generally taken from the second lagoon and conveyed to a small holding lagoon near the site. From there, it was applied to the test site by border-strip flooding. At times, effluent was withdrawn directly from the first or third lagoons and applied to the test sites.

The test and control sites are underlain by two aquifers. The aquifers are hydraulically connected under the test site but separated under the control site.

Wastewater had been applied to the test site for about 15 years preceding the study. For the last 10 years of this period, the test and control sites had been planted to Bromegrass and fertilized. Neither site had received pesticides [4].

Mesa, Arizona

The system design for the Mesa project closely follows the general design shown in Figure 1. The rates of wastewater delivery to the test site, as listed in Table 2, are based on historical data for 1965-1977. Throughout the project period, the crops grown at the test site were different from those grown at the control site [5].

Roswell, New Mexico

The Roswell project differed from the general system design in that two control sites were used. One of these, located in an area irrigated from an artesian aquifer and with soils dissimilar to the test site, was used to test groundwater quality upgradient of the test site (as "control" or baseline measurements) but not for monitoring other parameters. The second control site was also irrigated from an artesian aquifer. Its soil was similar to that of the test site, and the same crop (corn) was grown on each. The second site was used in a manner similar to the control sites on other projects.

Effluent from the Roswell treatment plant was discharged through a pipeline by gravity flow. Water was withdrawn from the line as needed by farmers for irrigation and the remainder was discharged into a surface waterway.

The test site was flood irrigated (border strip) from a concrete-lined ditch that runs above one edge of the site. A field adjacent to the test site had been watered with a combination of wastewater and groundwater for a number of years. Runoff from a 9.3 hectare (ha) [23 acre (a)] portion of this field drained onto the test site [6].

San Angelo, Texas

The San Angelo project differed markedly from the others. At the time the other five studies were initiated, a separate investigation was underway at San Angelo with separate funding and with different purposes, objectives, and methodology. Upon review of the ongoing San Angelo study, EPA concluded that this work, with some redirection, would produce data useful in EPA's investigation of slow-rate systems. Under an EPA grant, the San Angelo study was extended and modified to become the sixth slow-rate treatment project.

The San Angelo project was different with respect to both the design of the overall treatment system and the experimental design of the study. First, the test site was an integral part of the overall treatment system. Second, the test site was much larger in area (by a factor of six) than that of any other project, although the flow of applied wastewater was not proportionally larger than the others. Third, the treatment plant provided only primary treatment before the wastewater was conveyed to a series of three oxidation lagoons. The system also included a separate sludge lagoon.

From the standpoint of experimental design, the San Angelo project differed in that it included no control site where the rate of irrigation water application was monitored and crop samples taken. Instead, "control" measurements were made on groundwater from domestic wells located at distances ranging from 1.5 to 21 km (1 to 13 mi) from the test site. Groundwater at the test site was sampled at shallow wells on the site and deep wells at the boundary. Groundwater monitoring downgradient of the site was not reported. Instead, leachate samples were taken at several seepage creeks between the test site and the nearby Concho River. Seepage from the test site contributed an average of 12.5 percent of the flow volume of the river downstream of the site. River water quality upstream and downstream of the test site was monitored.

From an operational standpoint, this project differed in that the effluent applied to the test site (by the border strip method) was drawn from different parts of the treatment system. At times, the applied water was drawn directly from each lagoon, and occasionally the effluent from the primary treatment plant was applied directly to the land.

Crops included Bermuda grass, fescue, forage sorghum, and oats. These grasses were utilized for grazing and hay production. Within the portion of the test site planted to Bermuda grass, there were 27 experimental plots at random locations where fertilizers were applied at different rates and crop yields were measured [7].

Tooele, Utah

The Tooele project differed from all of the others in four significant respects. First, no groundwater data were acquired because no groundwater was detected within 33 m (108 ft) of the surface. Leachate in the soil at both the test site and control site was collected by means of porous cups at various levels and analyzed as in the other projects, but because of equipment problems this approach did not yield useful data (see Section 6). Second, at the Tooele project, much greater emphasis was placed on soil sampling and analysis than at the others. Third, a greater variety of row crops was grown at both the test and control sites than at the other projects. These were grown in garden plots. Major portions of the test and control sites were planted to alfalfa or pasture grasses. Fourth, both the test and control sites were located downwind of a large smelter.

The Tooele treatment plant provided secondary treatment. Its effluent was conveyed by earthen ditch to two holding reservoirs in series. Water for the test site was drawn from the second reservoir and applied to part of the plot (10.5 ha or 26 a) by sprinkler and to the remainder (1.7 ha or 4 a) by flooding. Prior to 1976, wastewater had been applied to the entire test site by flooding [8].

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SECTION 5

SAMPLING AND ANALYSIS

The principal objective of the six studies was to determine changes in the concentration of various pollutants in several media as a function of applied water quality, depth, and time. A secondary objective was to draw meaningful comparison among the results of these studies. The techniques used for collection, preparation, and analysis of the samples exercise a profound effect on the results obtained. Consequently, it is crucial that these techniques be reliable and consistent for all parameters (e.g., site, depth, time) used for establishing trends.

SAMPLING AND PREPARATION

Samples of applied water were collected either continuously over a 24-hour period or in a one-time "grab" mode. Leachate samples were collected by lysimeters. Samples of groundwater were collected from wells sunk to different depths. Collection of soil samples involved cutting cores or digging trenches and removing soil at the desired depths. Vegetation samples were obtained simply by cutting whole plants or selected portions thereof.

Samples were generally collected at several locations within the test and control areas to provide a representative measure of the entire site. Collection frequency varied from weekly (for rapidly changing parameters such as applied water quality) to once during the 12- to 18-month study period (for crops that accumulate the pollutants of interest). Table 3 lists the number of samples and frequency of collection at the six projects.

Several techniques were used to extract the pollutants from soil and vegetation samples for preparing a solution suitable for analysis. Extraction with water roughly simulates the action of rain, and gives an indication of the mobility of pollutants through the soil. Extraction with a mild inorganic acid solution such as 0.1 N HCl or an organic chelating acid simulates the

TABLE 3 SAMPLING PROTOCOLS

Location	Applied Water	Leachate	Groundwater	Soil	Vegetation
Camarillo	26 biweekly composites of daily samples during 13 months	48 biweekly composites of samples from several locations and two depths (50 + 100 cm) during 12 months	192 biweekly samples from 3 wells at 2 depths during 16 months	28 composites of 10 samples at 2 locations per site and 7 depths (1,3,10,30,100, 200,300 cm) twice during study period	8 composites of 5 sets of flowers and leaves of 2 species (lettuce and tomatoes), at 4 or 5 locations, once during study period
Dickinson	24-hour composite of sewage lagoon effluent and a grab sample from the Heart River	4 samples from 2 locations and 2 samples from a 3rd location	Composite of samples from 20 wells sampled 4 times during study period	6 composites of samples from 3 locations at each of 6 depths (1, 3,10,30,100,205-305 cm), twice during study period	Composites of 24 samples from 3 subareas, twice during study period
Mesa	As in Camarillo	As in Camarillo	As in Camarillo	As in Camarillo	3 composites of 5 samples of 3-4 crops, once during study period
Roswell	Composites of 4 samples 4 times during study period	Samples from 3 depths	Composites of 4 samples from 20 wells at test site and 5 wells at control site, 4 times during study period	As in Dickinson	As in Dickinson
San Angelo	Weekly and biweekly samples	Weekly and biweekly samples	Weekly and biweekly samples	Composites of 10 samples at test area & 5 samples at control area at 10 different depths	Samples collected 2-3 times during 2 growing seasons
Tooele	Varying frequency from weekly 24-hour composites to occasional grab samples	None	None	Samples at 26 locations and 6 depths	Samples collected once during growing season

1 in. = 2.54 cm

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SECTION 5

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action of a plant in obtaining minerals, and roughly represents the amount available to the plant. Finally, the "total" amount of an element present is determined after digestion of the sample with strong oxidizing agents such as nitric, perchloric, hydrochloric, or hydrofluoric acids. The specific sample preparation techniques used are presented in Table 4.

ANALYSIS

Most solids were determined gravimetrically. Nutrients and other inorganic ions were measured by titration, colorimetry, or electrometry. Heavy metals were generally analyzed by atomic absorption spectroscopy. The specific techniques employed for each pollutant in the several media sampled at each location are listed in Tables 5 and 6. Most techniques were drawn from, and are described in, four standard references [10 - 13].

UNIFORMITY, COMPARABILITY, AND OTHER CHARACTERISTICS OF FIELD DATA FROM THE SIX PROJECTS

The six slow-rate system studies summarized in this report were field investigations conducted by four contractors operating in different locations under widely diverse conditions. Their activities were conducted within the framework of commercial farming operations, and in some cases were constrained by the requirements of such operations.

The data produced by these investigations should not be viewed as the results of a rigorously controlled laboratory experiment. Field sampling equipment sometimes malfunctioned and needed measurements were not obtained. The six studies employed four somewhat distinct sets of sampling, sample preparation, and analytical techniques. Different analytical methods were sometimes employed to measure the same parameter at different project locations. Under these conditions it cannot be assumed that all measurement data are of uniform accuracy and reliability. Also, concentrations of a given element such as phosphorus are reported in different forms (for example, total phosphorus, soluble phosphorus, phosphate, or soluble phosphate) at different projects.

Because of these differences in methods of acquisition and processing of field data, portions of the very large quantity of data contained in the six

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TABLE 4 PREPARATION OF SOIL AND VEGETATION SAMPLES

	Extraction			Total Digestion
	Cation Exchange	Water Extraction	Acid Extraction	
Camarillo	Sodium saturation	Ground sample extracted with distilled water; soil-to-water ratio of 1:10.	Extraction with 10 times 0.1 N HCl	Digestion with HNO_3-$HClO_4$ and with HF
Dickinson	Extraction with 1N NH_4Ac and 95% ethanol	Extraction with distilled water	Extraction with triethanolamine, $CaCl_2$, and DTPA*	Digestion with HF, with 3:1 HCl-HNO_3 mixture (aqua regia), and re-dissolution with HCl
Mesa	Sodium saturation	Same as Camarillo	Same as in Camarillo	Same as in Camarillo
Roswell	Same as in Dickinson	Extraction with distilled water	Same as in Dickinson	Same as in Dickinson
San Angelo	Extraction with 1N NH_4Ac	Extraction with distilled water	Extraction with 1N HCl	Digestion with HNO_3-$HClO_4$
Tooele				Digestion with HNO_3-HClO and re-dissolution in 0.5 NH_4Cl

*DTPA = carboxy-methylimino bis-ethylenenitrilo-tetracetic acid.

Blank = information not given in project report.

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action of a plant in obtaining minerals, and roughly represents the amount available to the plant. Finally, the "total" amount of an element present is determined after digestion of the sample with strong oxidizing agents such as nitric, perchloric, hydrochloric, or hydrofluoric acids. The specific sample preparation techniques used are presented in Table 4.

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TABLE 5 ANALYTICAL TECHNIQUES FOR NON-METALS

Pollutant	Water						Soil						Vegetation			
Site:	C	D	M	R	S	T	C	D	M	R	S	T	C	D	M	R
TS, SS		Gr		Gr		Gr										
DS	Gr	Gr	Gr	Gr		Gr										
Conductivity	E	E	E	E		E					E	E				
$CO_3^=$, HCO_3^-		Ti		Ti		Ti					Ti					
Cl^-	Ti	E/Ti	Ti	E/Ti		✓	Ti		Ti				Ti'		Ti	
F^-	Co		Co				Co		Co							
S^-		E		E												
$SO_4^=$	Tu	Tu	Tu	Tu		Tu		Co		Co			Tu	Co	Tu	Co
pH		E		E	E	E	E	✓	E	✓	E					
DO		0		0		✓										
BOD		0		0	0	0										
COD		Ti		Ti	Ti	Ti										
TOC, SOC	Cm	Cm	Cm	Cm		Cm										
N-total	Di	Di	Di	Di	Di	Di	Di		Di		Di	Di				
$N\text{-}NH_3$		E		E	0	✓		E		E	0	0		E		E
$N\text{-}NO_3$	Co	E	Co	E	0	✓	Co	E	Co	E	Co	0		E		E
N-organic		E		E				E		E				E		E
P-total		Co		Co	0	✓	Co	Co	Co	Co	Co			✓		✓
$P\text{-}PO_4^≡$	Co	Co	Co	Co	0	✓	Co	Co	Co	Co	0	Co	Co		Co	
P-organic							Co		Co							
B	Co	Co	Co	Co			Co	Co	Co	Co			Co	Co	Co	Co
Pesticides		LC		LC		✓		LC		LC				GC		GC
Coliform	MT	PD	MT	PD	✓	✓	MT		MT				MT	PD	MT	PD
Protozoa	✓				✓		0		0		✓					
Nematodes	✓				✓		0		0		✓					

C - Camarillo
D - Dickinson
M - Mesa
R - Roswell
S - San Angelo
T - Tooele

Cm - Combustion
Co - Colorimetry
Di - Digestion
E - Electrometry
Gr - Gravimetry
Gc - Gas Chromatography

LC - Liquid chromatography
MT - Multiple tube ferm
0 - Other technique
PD - Petri dish count
Ti - Titration
Tu - Turbidimetry

✓ - Measurement reported but technique not identified
Blank - Measurement not reported

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TABLE 6 ANALYTICAL TECHNIQUES FOR METALS

Metal	Water						Soil						Vegetation					
Site:	C	D	M	R	S	T	C	D	M	R	S	T	C	D	M	R	S	T
Ag						AA	AA		AA									
Al		AA		AA		AA		AA		AA								
As	AA	AA	AA	AA		AA	AA	AA	AA	AA				AA		AA		
Ba	AA		AA				AA		AA				AA		AA			
Ca	FE	✓	FE	✓		✓	FE		FE				FE		FE			AA
Cd	AA	AA	AA	AA	AA	AA	AA	✓	AA	✓	AA	AA	AA		AA		AA	AA
Co		AA		AA				AA		AA								
Cr	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	
Cu	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA		AA		AA	AA
Fe		AA		AA		AA		AA		AA								AA
Hg		0		0		✓	0	0	0	0				0		0		
K	AA	AA	AA	AA		AA	AA	AA	AA	AA			AA		AA			AA
Mg	AA	AA	AA	AA		AA	AA	AA	AA	AA			AA		AA			
Mn		AA		AA		AA	AA	AA	AA	AA			AA	AA	AA	AA		
Mo	AA		AA				AA		AA				AA		AA			
Na	FE	✓	FE	✓		✓	FE	AA	FE	AA			FE	✓	FE	✓		AA
Ni	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA					AA	
Pb	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA		AA			AA
Se	AA	AA	AA	AA			AA	AA	AA	AA			AA	AA	AA	AA		
Zn	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA	AA

Key:
C - Camarillo
D - Dickinson
M - Mesa
R - Roswell
S - San Angelo
T - Tooele
AA - Atomic absorption spectroscopy
FE - Flame emission spectroscopy
0 - Other technique
✓ - Measurement reported but technique not identified
Blank - Measurement not reported

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project reports are not strictly comparable from one project to another. Measurement data presented in this summary report -- principally in the 20 data tables in Section 6 -- were selected to provide, to the maximum extent permitted by information in the project reports, a basis for valid comparisons and conclusions.

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SECTION 6

RESULTS AT THE SIX LOCATIONS

Measurements of pollutants and other parameters in applied wastewater and in the soil, vegetation, and groundwater media at the six project locations are presented in summary form in this section, and interpreted in the two succeeding sections. This section contains tabulations of data organized as described below. Section 7 contains comments and observations of the data for each project location. Section 8 discusses the transport of individual pollutants from the wastewater through the soil and groundwater, and the uptake of pollutants by crops.

ORGANIZATION OF DATA TABLES

The results of measurements of approximately 50 pollutants and other water quality parameters in the three media (soil, vegetation, and groundwater, including leachate) at the six locations (Camarillo, Dickinson, Mesa, Roswell, San Angelo, and Tooele) are presented in a series of 20 tables. The tables are grouped first by medium and then by pollutant category within each medium. The general pollutant categories are: nitrogen and phosphorus, organics, suspended and dissolved solids, alkali and alkaline earth metals, heavy metals, nonmetallic elements, and bacteriological indicators of pathogenic organisms.

Each table reports the concentrations of several pollutants in the applied water and in the selected locations within a given medium for each of the six projects (for example, at different depths in the groundwater or different parts of a crop plant). An inspection of the tables will convey this arrangement more clearly. The media-based approach is predicated on the assumption that most readers will prefer to access the data by medium rather than by pollutant or location.

The entries in the columns for each pollutant show four values: the concentrations at the test and control sites, the percent difference with

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respect to the control site value, and the significance level of the difference.* Tables 7 through 14 show these parameters in groundwater or leachate; Tables 15 through 21, in soils; and Tables 22 through 26, in vegetation. In cases where the values are not large enough to be detected by the analytical techniques used, the detection limits are reported but difference and significance level are not, as they have no meaning. In some instances, control site data were not available and comparisons were omitted or drawn between concentration measured upgradient and downgradient of the test site or at different times in the effluent application period. With a few duly noted exceptions, the units are parts per million (ppm), milligrams per liter (mg/l), or micrograms per gram (μg/g), which are considered as equivalent here.

DATA SELECTION

Each of the four investigating teams responsible for the six reports reviewed here had its own concept of balance, emphasis, and format in collecting and presenting the data. For example, the reports on the Dickinson and Roswell projects go into great detail on the effects of land treatment on water quality, but deal only briefly with effects on vegetation uptake. The San Angelo report devotes considerable attention to the interaction of the effluent with several soil types, but provides no control site measurements. The Tooele report contains very extensive data on the effects of effluent application on vegetation growth and pollutant uptake, but contains no groundwater quality data since there was no percolate to groundwater. The data presented in this summary often represent averages of data acquired over a range of conditions and were selected with a view toward providing a higher degree of consistency and balance, and permitting comparison of results from one project with another.

In addition to the general criteria of consistency and comparability, one specific criterion for selecting data for inclusion in the tables relates

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*Although the statistical techniques used to evaluate the significance of the differences between test and control site values are not identified in all project reports, those reports that make this identification indicate that the Student t-test is used. It is assumed that this technique is used for all of the projects.

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to the sample preparation and analysis. Concentrations of pollutants in the soil are analyzed by different techniques that reflect the bonding of the pollutant molecules to soil particles, and therefore serve to predict their transport and fate. The "total" and the "water-extractable" levels are the more important and are reported here in preference to the others, when they are available.

TABLE 7 CONCENTRATION OF NITROGEN AND PHOSPHORUS IN LEACHATE AND GROUNDWATER (mg/1)

	N-Kjeldahl				N-NO$_3^-$				N-NH$_4^+$				P-Total				P-PO$_4^{\equiv}$			
	Test***	Cont	%Δ	(SL)	Test	Cont***	%Δ	(SL)	Test	Cont	%Δ***	(SL)	Test	Cont	%Δ	(SL)***	Test	Cont	%Δ	(SL)
Camarillo																				
·Applied water	15.0	3.5	+330	(0.01-0.04)	4.6	2.1	+120	(0.05-0.1)									11.8	0.5	+2,260	(0.01-0.04)
·Leachate - 50cm	36.6	27.5	+ 33	(>0.1)	34.6	28.2	+ 23	(>0.1)									4.8	3.8	+26	(>0.1)
·Leachate - 100cm	47.5	34.1	+ 39	(>0.1)	53.0	32.5	+ 63	(0.05-0.1)									2.9	3.0	-3	(>0.1)
·Groundwater-top*	53.9	41.3	+ 31	(0.01-0.04)	52.8	39.9	+ 32	(0.01-0.04)									0.5	0.4	+25	(>0.1)
·Groundwater-bottom*	45.6	38.6	+ 18	(0.05-0.1)	44.3	38.2	+ 11	(0.05-0.1)									0.60	0.28	+114	(>0.1)
Dickinson																		(soluble)		
·Applied water					1.5	4.0	- 63		6.9	0.1	+6800		6.9	0.05	+13,700		3.8	<.01	+37,900	
·Groundwater					1.8	0.4	+350	(≤0.05)	0.4	0.3	+ 33	(>0.05)	0.06	0.07	-14	(>0.05)	0.03	0.05	-40	(>0.05)
Mesa																				
·Applied water	24.9	3.5	+611	(0.01-0.04)	1.8	2.7	- 38	(>0.1)									9.0	,0.5	+1740	(0.01-0.04)
·Leachate - 50cm																	5.0	1.0	+ 400	(>0.1)
·Leachate - 100cm																	4.2	3.6	+17	(>0.1)
·Groundwater-top*	15.2	9.1	+ 67	(0.05-0.1)	12.0	6.9	+ 74	(0.05-0.1)									1.7	1.0	+70	(>0.1)
·Groundwater-bottom*	11.9	7.1	+ 67	(0.01-0.04)	9.9	5.8	+ 71	(0.05-0.1)									2.1	1.2	+75	(>0.1)
Roswell		(Organic N)																(soluble)		
·Applied water	41.3	(total)****			1.6	1.2	+ 33	(>0.05)	23.3	0.1	+23,200	(≤.05)	7.95	0.01	+79,400	(≤.05)	6.47	0.05	+12,840	(≤.05)
·Groundwater<6m	0.7	soluble			13.0				0.2								0.08			
·Groundwater>6m	0.8				6.5	1.0	+550	(≤.05)	0.2	0.4	-50	(>.05)					0.21	0.11	+91	(>.05)
San Angelo		(N-Kjeldahl)																(dissolved)		
·Lagoon effluent	35.2				0.25				22.1				21.6				9.5			
·Groundwater<10m	<0.3				5.8				<0.3				0.06				0.04			
·Groundwater<10m	<0.3	<0.3			15.7	22.0	- 29		<0.3	<0.3			0.03	0.02	+50		0.02	0.01		
·River water**	0.7	0.7	0	(>0.05)	5.7	1.6	+256	(≤0.05)	<0.3	<0.3			0.08	0.06	+33	(>0.05)	0.024	0.017	+41	(>0.05)

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*Concentrations at the test site

**Upgradient/downgradient concentrations at test site

***Test = concentration at test site

Cont = concentration at control site

$$\%\Delta = \frac{\text{(concentration at test site) - (concentration at control site)}}{\text{concentration at control site}}$$

(SL) = significance level

****The value for total organic nitrogen in applied water (in Table 11 of Reference 5) appears, on review of analytical procedures in this reference, to represent total Kjeldahl-N. It is used as TKN in the sample calculation in Appendix B.

Orig' attached

TABLE 8 CONCENTRATIONS OF ORGANICS IN LEACHATE AND GROUNDWATER (mg/1)

	DO				BOD				COD				TOC				DOC			
Location/Depth	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo																				
·Applied Water													34.7	3.8	+813	(0.01-0.04)				
·Leachate - 50 cm													26.1	27.2	- 4	(>0.1)				
·Leachate - 100cm													19.1	29.4	- 35	(>0.1)				
·Groundwater-top*													13.0	9.0	+ 44	(>0.1)				
·Groundwater-bottom*													13.5	10.3	+ 31	(>0.1)				
Dickinson																				
.Applied Water	9.2	8.3	+ 11		42	7	500		248	60	+313		93	23	+304		38.2	18.0	+112	
.Groundwater	2.7	3.1	- 13	(>0.05)	1	<1			59	19	+211	(≤0.05)					30.6	10.7	+186	(<0.05)
Mesa																				
·Applied water													58.9	19.9	+200	(0.01-0.04)				
·Leachate - 50cm																				
·Leachate - 100cm																				
·Groundwater-top*													26.1	18.9	+ 38	(>0.1)				
·Groundwater-bottom*													31.1	31.3	- 1	(>0.1)				
Roswell																				
·Applied water	2.1	7.7	- 73	(>.05)	43	1.3	+3207	(>.05)	172	22	+662	(≤.05)	60.5				27.9	8.4	+232	(>.05)
·Groundwater<6m	2.1				<1				46								13.2			
·Groundwater>6m	1.9	1.6	+ 19	(>.05)	<1	1		(>.05)	58	45	+ 29	(>.05)					15.0	11.6	+ 29	(>.05)
San Angelo																				
·Lagoon effluent					119				340											
·Groundwater<10m					1.1				78											
·Groundwater>10m					0.8	1.2	- 33		46	17	+171									
·River water**					3.1	3.8	- 18		58	65	- 11									

*Upgradient/downgradient concentrations at the test site

**Upstream/downstream concentrations at the test site

Orig attache

TABLE 9 CONCENTRATIONS OF INORGANIC SALTS IN LEACHATE AND GROUNDWATER (mg/1), PLUS RELATED PHYSICAL AND CHEMICAL PROPERTIES

	Dissolved Solids				Chloride (Cl$^-$)				Fluoride (F$^-$)				Sulfate (SO$_4^=$)				Conductivity (μmhos)				pH (units)			
	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ'	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo																								
•Applied water	995	733	+ 36	(0.01-0.04)	166	73	+125	(0.01-0.04)	1.6	0.6	+ 160	(0.01-0.04)	194	227	- 15	(0.01-0.04)								
•Leachate- 50cm	1741	1996	- 13	(>0.1)	247	217	+ 14	(0.05-0.1)	0.7	1.1	- 32	(0.05-0.1)	267	434	- 38	(0.01-0.04)								
•Leachate-100cm	1920	2505	- 23	(0.01-0.04)	227	288	- 21	(0.05-0.01)	0.7	0.9	- 22	(0.05-0.1)	284	881	- 68	(0.01-0.04)								
•Groundwater-top*	3916	3004	+ 30	(0.01-0.04)	358	262	+ 37	(0.01-0.04)	1.23	1.02	+ 2	(>0.1)	1644	1379	+ 19	(0.05-0.1)								
•Groundwater-bottom*	4002	3524	+ 14	(0.01-0.04)	366	297	+ 23	(0.01-0.04)	1.1	1.3	- 15	(>0.1)	1586	1386	+ 14	(>0.1)								
Dickinson																								
•Applied water	1201	1119	+ 7		83	20	+315						359				1687	1680	0		8.7	8.8	- 1	
•Groundwater	4207	1334	+215	(≤0.05)	85	22	+286	(≤0.05)					2301	539	+327	(≤0.05)	4137	1972	+110	(≤0.05)	7.4	8.0	- 8	(≤0.05)
Mesa																								
•Applied water	1044	818	+ 27	(0.01-0.04)	356	254	+ 40	(0.01-0.04)	1.41	0.50	+182	(0.01-0.04)	67	54	+ 24	(0.01-0.04)								
•Leachate- 50cm	1507	1242	+ 21	(>0.01)	380	486	- 22	(>0.1)					110	144	- 24	(>0.1)								
•Leachate-100cm					316	354	- 11	(>0.1)	1.10	1.06	+ 4	(>0.1)												
•Groundwater-top*	1135	728	+ 56	(0.01-0.04)	340	234	+ 45	(0.01-0.04)	0.42	0.43	- 2	(>0.1)	84	66	+ 27	(0.05-0.1)								
•Groundwater-bottom*	1193	734	+ 63	(0.01-0.04)	357	247	+ 45	(0.01-0.04)	0.79	0.34	-132	(>0.1)	78	72	+ 8	(>0.1)								
Roswell																								
•Applied water	2194	2863	- 23	(≤.05)	681	911	+ 25	(>.05)					659	713	- 8	(>.05)	3170	3600	- 12	(>.05)	7.6	75	-90	(>.05)
•Groundwater<6m	5807				1673								1842				7431				7.1			
•Groundwater>6m	6396	6392	0	(>.05)	1904	2314	- 24	(≤.05)					1905	1979	- 4	(>.05)	8197	9260	- 11	(>.05)	7.1	73	-90	(≤.05)

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*Concentrations upgradient and downgradient of test site

Orig attached

TABLE 10 CONCENTRATIONS OF ALKALI AND ALKALINE EARTH METALS IN LEACHATE AND GROUNDWATER (mg/l)

	K				Na				Ba				Ca				Mg			
Location/Depth	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo																				
•Applied water	16.9	4.6	+265	(0.01-0.04)	212	88.4	+140	(0.01-0.04)	0.08	0.17	-53	(0.05-0.1)	54.7	49.6	+ 10	(>0.1)	33.7	40.1	- 16	(>0.1)
•Leachate - 50cm	26.9	15.4	+ 75	(0.01-0.04)	247	217	+ 14	(>0.1)	0.19	0.11	+73	(>0.1)	112	93.9	+ 19	(>0.1)	155	127	+ 22	(>0.1)
•Leachate - 100cm	16.1	12.4	+ 30	(0.01-0.04)	267	284	- 6	(>0.1)	0.23	0.22	+ 5	(>0.1)	74	195	- 62	(0.01-0.4)	121	135	- 10	(>0.1)
•Groundwater-top*	4.65	11.6	- 60	(0.01-0.04)	301	288	+ 5	(0.05-0.1)	0.14	0.13	+ 8	(>0.1)	198	178	+ 11	(>0.1)	280	72.6	+286	(0.01-0.04)
•Groundwater-bottom*	5.2	8.6	- 40	(0.05-0.1)	294	299	- 2	(>0.1)	0.16	0.13	+23	(>0.1)	190	160	+ 14	(>0.1)	295	243	+ 21	(>0.1)
Dickinson																				
•Applied water	24	12.4	+ 94		306	309	- 1						55	55	0		15	30	- 50	
•Groundwater	11.6	5.6	+107	(≤0.05)	593	422	+ 41	(≤0.05)					371	94	+295	(≤0.05)	51	17	+200	(≤0.05)
Mesa																				
•Applied water	18.1	6.4	+181	(0.01-0.04)	215	150	+ 43	(0.01-0.04)	0.16	0.13	+23	(>0.1)	46.8	42.5	+ 10	(>0.1)	41.8	37.4	+ 12	(>0.1)
•Leachate - 50cm					222	285	- 22	(>0.1)												
•Leachate - 100cm	15.6	15.6	0	(>0.1)	306	211	+ 45	(>0.1)	0.16	0.18	-11	(>0.1)					39.7	61.1	- 36	(0.05-0.1)
•Groundwater-top*	9.0	7.6	+ 18	(>0.1)	228	158	+ 44	(0.01-0.04)	0.24	0.15	+60	(>0.1)	60	31	+ 94	(0.01-0.04)	78	36	+118	(0.01-0.04)
•Groundwater-bottom*	11.7	8.4	+ 39	(>0.1)	217	158	+ 37	(0.01-0.04)	0.19	0.16	+19	(>0.1)	59	31	+ 90	(0.01-0.04)	84	40	+[illegible]	(0.01-0.04)
Roswell																				
•Applied water	14.7	6.1	+141	(≤.05)	466	408	+ 14	(>.05)					192	279	- 31	(>.05)	67	84	- 20	(>.05)
•Groundwater<6m	10.0				1073								503				160			
•Groundwater>6m	9.4	11.9	- 21	(>.05)	1122	1653	- 32	(≤.05)					550	436	+ 26	(>.05)	173	150	+ 15	(>.05)

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*Concentrations upgradient and downgradient of test site

a/ attchd

TABLE 11 CONCENTRATIONS OF HEAVY METALS (I) IN LEACHATE AND GROUNDWATER (mg/l)

	Al				Cd				Co				Cr				Cu			
	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo																				
•Applied water					0.02	0.01	+100	(>0.1)					0.02	0.03	- 33	(>0.1)	0.06	0.13	-54	(0.01-0.04)
•Leachate - 50cm					0.02	0.03	- 33	(>0.1)					0.05	0.02	+150	(0.05-0.1)	0.19	0.12	+58	(>0.1)
•Leachate - 100cm					0.02	0.02	0	(>0.1)					0.02	0.05	- 60	(0.05-0.1)	0.14	0.13	+ 8	(>0.1)
•Groundwater-top*					0.02	0.02	0	(>0.1)					0.07	0.09	- 22	(>0.1)	0.06	0.04	+50	(>0.1)
•Groundwater-bottom*					0.02	0.03	-33	(>0.1)					0.03	0.10	- 70	(0.05-0.1)	0.07	0.05	+40	(>0.1)
Dickinson																				
•Applied water	0.5	<3.3			<0.01	<0.01			<0.02	<0.02			<0.02	<0.02			<0.02	<0.02		
•Groundwater	0.6	2.0	-70	(≤0.05)	<0.01	<0.01			<0.02	<0.02			<0.02	<0.02			<0.034	<0.02		
Mesa																				
•Applied water					0.02	0.01	+100	(>0.1)					0.04	0.03	+ 33	(>0.1)	0.08	0.08	0	(>0.1)
•Leachate - 50cm					0.01	0.01	0	(>0.1)					0.02	0.03	- 33	(>0.1)				
•Leachate - 100cm					0.02	0.01	+100	(>0.1)					0.05	0.05	0	(>0.1)	0.06	0.16	-63	(>0.1)
•Groundwater-top*					0.01	0.01	0	(>0.1)					0.03	0.02	+ 50	(>0.1)	0.07	0.08	-13	(>0.1)
•Groundwater-bottom*					0.01	0.01	0	(>0.1)					0.03	0.03	0	(>0.1)	0.07	0.08	-13	(>0.1)
Roswell																				
•Applied water	0.5	0.5	0	(>.05)	<0.02	<0.02			<0.05	<0.05			0.02	0.01	+100	(>.05)	0.07	0.05		(>.05)
•Groundwater<6m	1.4				<0.02				<0.05				<0.02				0.061			
•Groundwater>6m	0.9	1.1	-18	(>.05)	<0.02	<0.02			<0.05	<0.05			<0.02	<0.02	0		0.065	0.053		(>.05)
San Angelo																				
•Lagoon effluent					<0.004								0.124				0.30			
•Groundwater<10m					<0.004								<0.005				0.15			
•Groundwater>10m					<0.004	0.005							<0.005	<0.005			0.021	0.016	+31	
•River water*					<0.004	<0.004							<0.005	<0.005			0.012	0.020	-40	

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*Concentrations upgradient and downgradient of test site

TABLE 12 CONCENTRATIONS OF HEAVY METALS (II) IN LEACHATE AND GROUNDWATER (mg/1)

	Fe				Hg				Mn/Mo				Ni				Pb				Zn			
Location/Depth	**Test**	**Cont**	**%**	**(SL)**	**Test**	**Cont**	**%**	**(SL)**	**Test**	**Cont**	**%**	**(SL)**	**Test**	**Cont**	**%**	**(SL)**	**Test**	**Cont**	**%**	**(SL)**	**Test**	**Cont**	**%**	**(SL)**
Camarillo										(Mo)														
•Applied water									0.11	0.10	+ 10	(>0.1)	0.1	0.05	+100	(0.05-0.1)	0.05	0.08	-38	(>0.1)	0.05	0.07	- 29	(>0.1)
•Leachate - 50cm									0.12	0.13	- 8	(>0.1)	0.1	0.07	+ 43	(>0.1)	0.12	0.07	+71	(0.05-0.1)	0.41	0.43	- 5	(>0.1)
•Leachate - 100cm									0.16	0.10	+ 60	(0.05-0.1)	0.07	0.05	- 40	(>0.1)	0.09	0.13	-31	(0.05-0.1)	0.25	0.59	- 58	(0.01-0.04)
•Groundwater-top*									0.22	0.17	+ 29	(>0.1)	0.10	0.10	0	(>0.1)	0.11	0.09	+22	(>0.1)	0.05	0.05	0	(>0.1)
•Groundwater-bottom*									0.23	0.19	+ 21	(>0.1)	0.10	0.10	0	(>0.1)	0.12	0.09	+33	(>0.1)	0.08	0.07	+ 16	(>0.1)
Dickinson										(Mn)														
•Applied water	0.7	<0.1	+600		<0.001	<0.001			<0.05	0.23			<0.05	<0.05			<0.1	<0.1			<0.05	<0.05		
•Groundwater	1.8	2.2	- 18	(>0.05)	<0.0001	<0.0001			1.0	0.2	+400	(≤0.05)	<0.05	<0.05			<0.1	<0.1			0.19	0.06	+217	(≤0.05)
Mesa										(Mo)														
•Applied water									0.10	0.10	0	(>0.1)	0.07	0.05	+ 40	(>0.1)					<0.06	<0.06	0	
•Leachate - 50cm													0.05	0.09	- 44	(>0.1)	0.07	0.12	-42	(>0.1)	0.19	0.32	- 41	(>0.1)
•Leachate - 100cm									0.10	0.10	0	(>0.1)	0.10	0.31	- 68	(0.05-0.1)	0.06	0.09	-33	(>0.1)	0.16	0.37	- 57	(0.01-0.04)
•Groundwater-top*									0.12	0.12	0	(>0.1)	0.05	0.05	0	(>0.1)	0.14	0.19	-26	(>0.1)	0.22	0.18	+ 22	(>0.1)
•Groundwater-bottom*									0.10	0.11	- 9	(>0.1)	0.05	0.05	0	(>0.1)	0.19	0.13	+46	(>0.1)	0.26	0.32	- 19	(>0.1)
Roswell										(Mn)														
•Applied water	0.64	0.35	+ 83	(>0.05)	0.0006	<0.0005			<0.05	<0.05			<0.05	<0.05			<0.10	<0.10			0.08	<0.05		
•Groundwater<6m	95.8				<0.0005				0.11				0.062				<0.10				0.137			
•Groundwater>6m	3.4	7.5	- 55	(>0.05)	<0.0005	<0.0005			0.11	0.15	- 27	(>0.05)	0.068	0.063	+ 8	(>0.05)	<0.10	<0.10			0.117	0.086	+ 36	(>0.05)
San Angelo																								
•Lagoon effluent													0.077				0.07				0.19			
•Groundwater<10m													0.017				<0.05				0.23			
•Groundwater>10m													0.015	0.025	- 40		<0.05	<0.05			0.20	1.57	- 87	
•River water**													<0.01	<0.01			<0.05	<0.05			0.123	0.098	+ 26	

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*Upgradient/downgradient concentrations at the test site
**Upstream/downstream concentrations at the test site

TABLE 13 CONCENTRATIONS OF NONMETALLIC ELEMENTS IN LEACHATE AND GROUNDWATER (mg/l)

	As				B				Se			
Location/Depth	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo												
•Applied water	0.01	0.01	0	(>0.1)	0.85	0.23	+270	(0.01-0.04)	0.01	0.01	0	(>0.1)
•Leachate-50cm	0.01	0.02	-50	(>0.1)	0.89	0.74	+20	(>0.1)	0.01	0.02	-50	(>0.1)
•Leachate-100cm	0.01	0.01	0	(>0.1)	1.02	0.65	+57	(0.01-0.04)	0.01	0.01	0	(>0.1)
•Groundwater-top*	0.01	0.01	0	(>0.1)	0.99	0.88	+13	(>0.1)	0.01	0.01	0	(>0.1)
•Groundwater-bottom*	0.01	0.01	0	(>0.1)	1.5	1.14	-8	(>0.1)	0.01	0.01	0	(>0.1)
Dickinson												
•Applied water	0.006	<0.005			0.92	0.25	+268		0.007	0.005	+40	
•Groundwater	0.014	0.005	+180	(≤0.05)	0.71	0.59	+20	(>0.05)	0.021	0.006	+250	(≤0.05)
Mesa												
•Applied water	0.02	0.01	+100	(>0.1)	0.44	0.19	+130	(0.01-0.04)	0.01	0.01	0	(>0.1)
•Leachate-50cm	0.01	0.01	0	(>0.1)	0.34	0.45	-24	(>0.1)	0.01	0.01	0	(>0.1)
•Leachate-100cm	0.01	0.01	0	(>0.1)	0.48	0.22	+118	(>0.1)	0.01	0.01	0	(>0.1)
•Groundwater-top*	0.02	0.02	0	(>0.1)	0.6	0.32	+88	(0.01-0.04)	0.01	0.01	0	(>0.1)
•Groundwater-bottom*	0.02	0.03	-33	(>0.1)	0.61	0.29	+110	(0.01-0.04)	0.01	0.01	0	(>0.1)
Roswell												
•Applied water	<0.02	<0.02			0.34	0.16	+113	(>0.05)	<0.01	<0.01		
•Groundwater<6m	<0.02				0.40				0.029			
•Groundwater>6m	<0.02	0.026			0.35	0.24	+46	(>0.05)	0.030	0.052	-42	(≤0.05)

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*Concentrations upgradient and downgradient of test site

TABLE 14 CONCENTRATIONS OF PATHOGENS AND INDICATOR ORGANISMS IN LEACHATE AND GROUNDWATER (MPN/100 ml)

	Total Coliform				Fecal Coliform			
	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo								
•Applied water	57,000	<2			220	<2		
•Leachate-50cm	7	4	+75	(>0.1)	<2	<2		
•Leachate-100cm	29	27	+7	(>0.1)	<2	4		
•Groundwater-top*	49	<2			<2	<2		
•Groundwater-bottom*	410	<2			<2	<2		
Dickinson								
•Applied water		533				33		
•Groundwater	59	511	-88		0	0		
Mesa								
•Applied water	3×10^6	11×10^3			1×10^5	1×10^3		
•Leachate-50cm	<2	20	-90	(>0.1)	<2	<2		
•Leachate-100cm	9	60	-85	(0.01-0.04)	9	25	-64	(>0.1)
Roswell								
•Applied water					?	3		
•Groundwater<6m					52			
•Groundwater>6m					6	2	+200	(>0.05)

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*Concentrations upgradient and downgradient of test site

TABLE 15 CONCENTRATIONS OF NITROGEN AND PHOSPHORUS IN SOIL (μg/g)

	N-Total (TD)**				$N\text{-}NO_3^-$ (WE)				$N\text{-}NH_4^+$				P-total				$P\text{-}PO_4^{\equiv}$				P-organic			
Location/Depth	**Test**	**Cont**	**% Δ**	**(SL)**	**Test**	**Cont**	**% Δ**	**(SL)**	**Test**	**Cont**	**% Δ**	**(SL)**	**Test**	**Cont**	**% Δ**	**(SL)**	**Test**	**Cont**	**% Δ**	**(SL)**	**Test**	**Cont**	**% Δ**	**(SL)**
Camarillo														(AE)**				(WE)**				(TD)		
•Applied water	15.0	3.5	+329	(0.01-0.04)	4.6	2.1	+120	(0.05-0.01)									11.8	0.5	+2,260	(0.01-0.04)				
•Soil* 1-300cm	579	970	-40	(0.01-0.04)	49	49		(>0.1)					340	743	-54	(0.01-0.04)	10	13	-23	(>0.1)	92	136	- 32	(>0.1)
•Soil 1-300cm	579	468	+24	(>0.1)	49.3	49.7	-1	(>0.1)					340	249	+37	(0.01-0.04)	10.0	11.4	-12	(>0.1)	92	136	- 32	(>0.1)
•Soil 1-10cm	801	685	+17		66.3	47.3	+40						133	165	-19		16.3	21.3	-23		134	165	- 18	
•Soil 30cm	531	--			69	--							115	<20			13	31	-58		115	<20		
•Soil 100cm	536	317	+69		47	57	-18						70	75	-7		7.3	22	-67		70	75	- 7	
•Soil 300cm	319	266	+20		20	63	-68						<20	100			<1	<1			<20	100		
Dickinson		(organic N)				(inorganic N)								(TD)**				(available P)						
•Applied water	3.4	1.3	+162		8.4	4.1	+105						6.9	0.05	+13,700		4.8	0.03	+15,900					
•Soil 0-300cm	1093	726	+51		28.9	25.7	+12						589	544	+8		35	41	-15					
•Soil 0-10cm	2987	1726	+73	(>0.05)	41.3	37.7	+10	(>0.05)					778	622	+25	(≤0.05)	90	87	+3	(>0.05)				
•Soil 30cm	768	545	+41	(>0.05)	24.3	28.0	-13	(>0.05)					574	529	+9	(>0.05)	30	46	-35	(>0.05)				
•Soil 100cm	395	359	+10	(>0.05)	29.4	18.3	+61	(>0.05)					554	565	-2	(>0.05)	14	18	-22	(>0.05)				
•Soil 300cm	222	274	-19	(>0.05)	20.4	18.6	+10	(>0.05)					450	459	-2	(>0.05)	6	11	-45	(>0.05)				
Mesa		(N-Kjeldahl)												(AE)				(WE)				(TD)		
•Applied water	24.9	3.5	+600	(0.01-0.04)	1.8	2.7	-38	(>0.1)									9.0	0.5	+1740	(0.01-0.04)				
•Soil* 1-300cm	142	543	-74	(0.01-0.04)	23.7	23.7	0						56.7	909	-94	(0.01-0.04)	15	16	-7	(0.01-0.04)	140	106	+ 32	(0.01-0.04)
•Soil 1-300cm	142	395	-64	(0.01-0.04)	23.7	42.3	-44	(>0.1)					56.7	20.6	-175	(0.01-0.04)	15	6.4	+134	(0.01-0.04)	140	77	+ 82	(0.01-0.04)
•Soil 1-10cm	261	672	-61		37	80	-54						80	27	+196		20	4	+400		103	125	+ 46	
•Soil 30cm	79	252	-69		26	9.5	+174						26	26	0		14	3.3	+324		105	55	+ 91	
•Soil 100cm	101	243	-58		17	6.3	+170						31	16	+94		14	3.9	+239		60	70	- 14	
•Soil 300cm	14	120	-88		4.4	29	-85						125	15	+733		6	11	-45		140	30	+367	

*Final/initial concentrations at the test site
**TD-total digestible; WE-water extractable; AE-acid extractable

CONTINUED

Q's attached

TABLE 15 (Concluded)

Location/Depth	N-Total (TD)**				$N\text{-}NO_3^-$ (WE)				$N\text{-}NH_4^+$				P-total				$P\text{-}PO_4^{\equiv}$				P-organic			
	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont % Δ (TD)		(SL)
Roswell		(organic N)				(inorganic N)								(TD)				(available P)						
•Applied water	41.3												8.0	0.01	+79,900	(≤0.05)	6.9	0.12	+5,650	(≤0.05)				
•Soil 0-300cm	812	693	+17		42.6	29.6	+44						1053	855	+23		20	9	+122					
•Soil 0-10cm	1777	1220	+46	(≤0.05)	56.5	32.5	+74	(≤0.05)					1635	1103	+48	(≤0.05)	56	18	+211	(≤0.05)				
•Soil 30cm	859	764	+12	(>0.05)	56	32.9	+70	(>0.05)					1174	855	+37	(>0.05)	12	9	+33	(>0.05)				
•Soil 100cm	350	502	-30	(>0.05)	27.2	23.7	+15	(>0.05)					655	795	-18	(>0.05)	5	9	-44	(>0.05)				
•Soil 300cm	260	287	-9	(>0.05)	30.5	29.4	+4	(>0.05)					748	665	+12	(>0.05)	6	1	+500	(>0.05)				
San Angelo		(N-Kjeldahl)																(dissolved)						
•Applied water	35.2				0.25				22.1				21.6				9.5							
•Soil 0-20cm (Kg/ha)	4430	3905	+13		48	11	+336		18	5	+260		2735	1119	+144		51	3	+1600					
Tooele														(AE)										
•Applied water	7.4	0.75	+885		5.8	0.46	+1161		4.6	0.05	+9100		9.3	0.06	+15,733									
•Soil 0-200cm	1209	1122	+8		10.2	6.2	+65		3.7	3.3	+12		62.6	8.9	+604									
•Soil 0-11cm	2,115	1,960	+8		17.1	9.6	+78		5.8	4.4	+32		102.5	16	+541									
•Soil 28-32cm	834	920	-9		10.2	6.7	+52		2.0	4.5	-56		65.7	7.3	+800									
•Soil 95/105cm	397	250	+59		4.9	4.9	0		1.2	2.1	-43		6.0	2.7	+122									
•Soil 295-305cm	120	130	-8		3.5	3.0	+17		1.7	—			12.3											

* Final/initial concentrations at the test site

** TD-total digestible; WE-water extractable; AE-acid extractable

TABLE 16 CONCENTRATIONS OF HALIDES IN SOIL (μg/g)

Location/Depth	Cl⁻ Test	Cl⁻ Cont	Cl⁻ % Δ	Cl⁻ (SL)	F⁻ Test	F⁻ Cont	F⁻ % Δ	F⁻ (SL)
Camarillo								
•Applied water	166	73	+125	(0.01-0.04)	1.6	0.6	+160	(0.01-0.04)
•Soil* 1-300cm	200	161	+ 24	(>0.01)	6.4	12.7	- 50	(0.01-0.04)
•Soil 1-300cm	200	140	+ 34	(0.05-0.01)	6.4	19.9	- 68	(0.01-0.04)
•Soil 1-10cm	263	183	+ 44		5.7	14.3	- 60	
•Soil 30cm	155	135	+ 15		5	23	- 78	
•Soil 100cm	165	124	+ 33		8	27	- 70	
•Soil 300cm	166	124	+ 34		7	19	- 63	
Mesa								
•Applied water	356	254	+ 40	(0.01-0.04)	1.41	0.5	+182	(0.01-0.04)
•Soil* 1-300cm	116	53	+119	(>0.1)	2.1	3.7	- 42	(>0.1)
•Soil 1-300cm	116	191	- 39	(>0.1)	2	6	- 67	(0.01-0.04)
•Soil 1-10cm	193	241	- 20		3.3	3.7	- 11	
•Soil 30cm	100	100	0		1	2	- 50	
•Soil 100cm	87	100	- 13		2	5	- 60	
•Soil 300cm	10	325	- 97		1	10	- 90	

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*Final/initial concentrations at the test site

TABLE 16 CONCENTRATIONS OF HALIDES IN SOIL (μg/g)

	Cl^-				F^-			
Location/Depth	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo								
•Applied water	166	73	+125	(0.01-0.04)	1.6	0.6	+160	(0.01-0.04)
•Soil* 1-300cm	200	161	+ 24	(>0.01)	6.4	12.7	- 50	(0.01-0.04)
•Soil 1-300cm	200	140	+ 34	(0.05-0.01)	6.4	19.9	- 68	(0.01-0.04)
•Soil 1-10cm	263	183	+ 44		5.7	14.3	- 60	
•Soil 30cm	155	135	+ 15		5	23	- 78	
•Soil 100cm	165	124	+ 33		8	27	- 70	
•Soil 300cm	166	124	+ 34		7	19	- 63	
Mesa								
•Applied water	356	254	+ 40	(0.01-0.04)	1.41	0.5	+182	(0.01-0.04)
•Soil* 1-300cm	116	53	+119	(>0.1)	2.1	3.7	- 42	(>0.1)
•Soil 1-300cm	116	191	- 39	(>0.1)	2	6	- 67	(0.01-0.04)
•Soil 1-10cm	193	241	- 20		3.3	3.7	- 11	
•Soil 30cm	100	100	0		1	2	- 50	
•Soil 100cm	87	100	- 13		2	5	- 60	
•Soil 300cm	10	325	- 97		1	10	- 90	

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*Final/initial concentrations at the test site

TABLE 17 CONCENTRATIONS OF ALKALI AND ALKALINE EARTH METALS IN SOIL (μg/g)

	K				Na				Ba				Ca				Mg				CEC (meq/g)			
Location/Depth	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo		(WE)**				(WE)				(TD)				(WE)				(WE)						
•Applied water	16.9	4.6	+265	(0.01-0.04)	212	88.4	+140	(0.01-0.04)	0.08	0.17	-53	(0.05-0.01)	54.7	49.6	+10	(>0.1)	33.7	40.1	-16	(>0.1)				
•Soil* 1-300cm	64	82	- 22	(>0.1)	281	229	+ 23	(0.01-0.04)	521	1015	-49	(0.01-0.04)	35	87	-60	(0.01-0.04)	45	61	-26	(>0.1)	0.29	0.14	+103	(0.01-0.04)
•Soil 1-300cm	64	67	- 4	(>0.1)	281	199	+ 41	(0.01-0.04)	521	816	-36	(0.01-0.04)	35	53	-34	(>0.1)	45	31	+48	(>0.1)	0.29	0.24	+21	(6.01-0.04)
•Soil 1-10cm	123	95.3	+ 29		272	197	+ 38		432	813	-47		61	13	+369		77	24.5	+214		0.29	0.27	+7	
•Soil 30cm	34	117	- 71		215	185	+ 16		691	822	-16		17	4	+325		28	12	+133		0.24	0.21	+12	
•Soil 100cm	22	14	+ 57		320	210	+ 52		397	821	-52		16	58	-72		21	37	-43		0.37	0.20	+88	
•Soil 300cm	11	29	- 62		300	205	+ 46		563	767	-27		14	99	-86		22	37	-40		0.29	0.23	+23	
Dickinson		(TD)**				(TD)								(TD)				(TD)						
•Applied water	24	12.4	+ 94		306	309	- 1						55	55	0		15	30	-50					
•Soil 0-300cm	5,400	6,100	- 11		10,900	11,700	- 7						5,400	4,300	+26		5,950	5,000	+19		0.15	0.10	+50	
•Soil 0-10cm'	5,500	6,400	- 14	(≤0.05)	10,300	11,800	- 13	(>0.05)					3,000	3,200	- 6	(>0.05)	6,000	5,200	+15	(>0.05)	0.22	0.12	+83	(≤0.05)
•Soil 30cm	5,500	6,200	- 11	(>0.05)	11,000	11,600	- 5	(>0.05)					5,300	3,100	+71	(>0.05)	6,000	4,600	+30	(>0.05)	0.16	0.10	+60	(>0.05)
•Soil 100cm	5,500	6,200	- 11	(>0.05)	10,500	12,000	- 13	(>0.05)					6,300	4,900	+29	(>0.05)	6,300	5,200	+21	(>0.05)	0.13	0.09	+44	(>0.05)
•Soil 300cm	5,200	5,600	- 7	(>0.05)	11,600	11,200	+ 4	(>0.05)					7,000	5,900	+19	(>0.05)	5,500	5,100	+8	(>0.05)	0.10	0.10	0	(>0.05)
Mesa		(WE)				(WE)				(TD)				(WE)				(WE)						
•Applied water	18.1	6.4	+181	(0.01-0.04)	215	150	+ 43	(0.01-0.04)	0.16	0.13	+23	(>0.1)	46.8	42.5	+10	(>0.1)	41.8	37.4	+12	(>0.1)				
•Soil* 1-300cm	92	67	+ 38	(0.01-0.04)	320	120	+167	(0.01-0.04)	442	550	-20	(0.01-0.04)	6.4	22	-71	(0.01-0.04)	10.9	27	-59	(0.01-0.04)	0.11	0.20	-45	(0.01-0.04)
•Soil 1-300cm	92	173	- 47	(0.01-0.04)	320	525	- 39	(0.05-0.1)	442	831	-47	(0.01-0.04)	6.4	6.4	0		10.9	21.5	-50	(0.05-0.1)	0.11	0.21	-47	(0.10-0.04)
•Soil 1-10cm	129	136	- 5		443	403	+ 10		472	815	-73		4.9	9.8	-50		13.8	28	-51		0.13	0.26	-48	
•Soil 30cm	74	93	- 20		299	306	- 2		467	1057	-56		5.7	7.5	-24		8.8	9.9	-11		0.14	0.20	-28	
•Soil 100cm	71	170	- 58		266	443	- 40		413	1023	-60		6.5	5.2	+25		7.9	11.8	-33		0.10	0.24	-57	
•Soil 300cm	45	250	- 82		161	879	- 82		411	709	-42		6.8	3.1	+119		7.6	17.4	-56		0.7	0.14	-48	
Roswell		(TD)				(TD)								(TD)				(TD)						
•Applied water	14.7	6.1	+141	(≤0.05)	466	408	+ 14	(>0.05)					192	279	-31	(>0.05)	67	84	-20	(>0.05)				
•Soil 0-300cm	11,200	11,500	- 3		5,100	6,300	- 19						31,100	41,000	-24		5,100	6,300	-19		0.30	0.26	+15	
•Soil 0-10cm	11,300	12,900	- 12	(>0.05)	5,500	6,600	- 17	(≤0.05)					29,000	31,000	-6	(>0.05)	5,400	6,100	-11	(>0.05)	0.31	0.26	+19	(≤0.05)
•Soil 30cm	11,100	11,400	- 3	(>0.05)	5,000	6,800	- 26	(≤0.05)					32,000	38,000	-16	(>0.05)	5,400	7,100	-24	(>0.05)	0.30	0.26	+15	(>0.05)
•Soil 100cm	11,100	12,200	- 9	(>0.05)	4,500	6,000	- 25	(>0.05)					37,000	44,000	-16	(>0.05)	5,600	6,300	-11	(>0.05)	0.32	0.26	+23	(≤0.05)
•Soil 300cm	11,200	9,400	+ 19	(>0 05)	5,400	5,700	- 5	(>0.05)					27,000	51,000	-47	(≤0.05)	4,000	5,600	-29	(>0.05)	0.26	0.27	-4	(>0.05)

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*Final/initial concentrations at the test site

**TD total digestible; WE water-extractable

TABLE 18 CONCENTRATIONS OF HEAVY METALS (I) IN SOIL (μg/g)

	Al (TD)**				Cd/Co				Cr (TD)				Cu(TD)				Fe (TD)			
	Test	Cont	% Δ	(SL)	Test	Cont Cd	% Δ (TD)	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo																				
•Applied water					0.02	0.01	+100	(>0.1)	0.02	0.03	-33	(>0.1)	0.06	0.13	-54	(0.01-0.04)				
•Soil* 1-300cm					<5	≥5.1	-2	(>0.1)	162	120	+35	(0.01-0.04)	31	27	+15	(0.05-0.1)				
•Soil 1-300cm					<5	<5			162	167	-3	(>0.1)	31	39	-21	(0.01-0.04)				
•Soil 1-10cm					3	<5			154	157	-2		33	46	-28					
•Soil 30cm					<5	<5			123	143	-14		23	40	-43					
•Soil 100cm					<5	<5			158	189	-16		29	36	-19					
•Soil 300cm					<5	<5			235	226	+4		35	34	+3					
Dickinson					Co (TD)															
•Applied water	0.5	<0.3			<0.02	<0.02			<0.02	<0.02			<0.02	<0.02			0.7	<0.1		
•Soil 0-300cm	45,800	35,800	+28		4.9	3.9	+26		33	33	0		15	10.5	+43		9,600	8.500	+13	
•Soil 0-10cm	43,000	31,000	+39	(>0.05)	4.9	3.7	+32	(≤0.05)	35	27	+30	(≤0.05)	16.8	8.5	+98	(≤0.05)	10,200	8,500	+20	(>0.05)
•Soil 30cm	48,000	38,000	+26	(>0.05)	4.7	3.1	+52	(>0.05)	32	31	+3	(>0.05)	14	8.6	+63	(≤0.05)	8,900	8,300	+7	(>0.05)
•Soil 100cm	48,000	39,000	+23	(>0.05)	5.5	5.0	+10	(>0.05)	34	32	+6	(>0.05)	163	12	+36	(>0.05)	9,600	9,100	+5	(>0.05)
•Soil 300cm	44,000	35,000	+26	(>0.05)	4.4	3.8	+16	(>0.05)	31	40	-23	(>0.05)	13	12.7	+2	(>0.05)	9,500	8,300	+14	(>0.05)
Mesa					Cd (TD)															
•Applied water					0.02	0.01	+100	(>0.1)	0.04	0.03	+33	(>0.1)	0.08	0.08	0					
•Soil* 1-300cm					<5	>6.1	-17	(0.01-0.04)	241	515	-53	(0.01-0.04)	31	259	-88	(0.01-0.04)				
•Soil 1-300cm					<5	<5			241	402	-40	(0.01-0.04)	31	53	-42	(0.01-0.04)				
•Soil 1-10cm					<5	<5			226	372	-39		33	53	-38					
•Soil 30cm					<5	<5			233	401	-42		35	56	-38					
•Soil 100cm					<5	<5			213	407	-48		23	63	-63					
•Soil 300cm					<5	<5			297	484	-39		42	48	-13					

* Final/initial concentrations at the test site
** TD-total digestible; AE-acid extractable

CONTINUED

TABLE 18 (Concluded)

	Al (TD)**				Cd/Co				Cr (TD)				Cu(TD)				Fe (TD)			
	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Roswell						Co (TD)														
•Applied water *	0.5	0.5	0		<0.05	<0.05			0.02	0.01	+100	(>0.05)	0.07	0.05	+40	(>0.05)	0.64	0.35	+83	(>0.05)
•Soil 0-300cm	22,800	18,800	+21		9.8	8.5	+15		31.2	26.5	+18		18.8	18.8	0		30,000	26,000	+15	
•Soil 0-10cm	22,000	21,000	+5	(>0.05)	10	9	+11	(>0.05)	32	28	+14		19	18	+6		27,000	24,000	-13	(>0.05)
•Soil 30cm	24,000	22,000	+9	(>0.05)	9	7	+29	(>0.05)	32	28	+14		19	19	0		25,000	27,000	-7	(>0.05)
•Soil 100cm	20,000	15,000	+33	(>0.05)	8	8	0	(>0.05)	30	26	+15		17	20	-15		31,000	22,000	+41	(>0.05)
•Soil 300cm	25,000	17,000	+47	(>0.05)	12	10	+20	(>0.05)	31	24	+29		20	18	+11		37,000	30,000	+23	(>0.05)
San Angelo						Cd (AE)**			(AE)				(AE)							
•Applied water					<0.004				0.124				0.30							
•Soil					0.48	0.38	+21		0.49	0.21	+133		0.9	0.8	+13					
Tooele																				
•Applied water									0.006	0.005	+20	(>0.05)	0.009	0.006	+50	(>0.05)				
•Soil 0-305cm									25.3	22.7	+11		18.6	17.3	+8					
•Soil 0-11cm									26.8	25.6	+5		26.1	25.6	+2					
•Soil 28-32cm									30.1	26.2	+15		17.2	16.1	+7					
•Soil 95-105cm									26.5	21.1	+26		14.3	12.9	+11					
•Soil 295/305cm									16.7	16.5	+1		11.4	10.7	+7					

* Final/initial concentrations at the test site
** TD-total digestible; AE-acid extractable

TABLE 19 CONCENTRATIONS OF HEAVY METALS (II) IN SOIL (μg/g)

	Hg (TD)**				Mn (TD)				Ni (TD)				Pb (TD)				Zn (TD)			
Location/Depth	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo																				
•Applied water									0.10	0.05	+100	(0.05-0.1)	0.05	0.08	-38	(>0.1)	0.03	0.07	-29	(>0.1)
•Soil* 1-300cm	<0.5	<0.5			533	413	+29	(0.01-0.04)	77	85	-9	(0.01-0.04)	34	54	-37	(0.01-0.04)				
•Soil 1-300cm	<0.5	<0.5			533	485	+10	(0.01-0.04)	77	72	+7	(>0.1)	34	95	-64		103	94	+10	(>0.1)
•Soil 1-10cm	<0.5	<0.5			530	477	+11		79	76	+4		36	166	-78		102	93	+10	
•Soil 30cm	<0.5	<0.5			525	461	+14		77	68	+13		45	64	-30		98	87	+13	
•Soil 100cm	<0.5	<0.5			535	499	+7		87	66	+32		22	52	-58		138	105	+31	
•Soil 300cm	<0.5	<0.5			519	501	+4		64	73	-12		37	30	+21		91	89	+2	
Dickinson																				
•Applied water	<0.001	<0.001			<0.05	0.23			<0.05	<0.05			<0.1	<0.1			<0.05	<0.05		
•Soil 0-300cm	<0.05	<0.05			266	210	+27		14.8	11.4	+30		<10	<10			72.5	62.5	+16	
•Soil 0-10cm	<0.05	<0.05			301	209	+44	(≤0.05)	15.1	8.8	+72	(≤0.05)	<10	<10			83	68	+22	(>0.05)
•Soil 30cm	<0.05	<0.05			248	203	+22	(>0.05)	15.3	12	+27	(>0.05)	<10	<10			67	59	+14	(>0.05)
•Soil 100cm	<0.05	<0.05			277	254	+9	(>0.05)	14.3	12.7	+13	(>0.05)	<10	<10			74	63	+17	(>0.05)
•Soil 300cm	<0.05	<0.05			238	213	+12	(>0.05)	14.3	12.1	+18	(>0.05)	<10	<10			66	60	+10	(>0.05)
Mesa																				
•Applied water									0.07	0.05	+40	(>0.1)								
•Soil* 0-300cm	<0.5	<0.5			646	209	+209	(0.01-0.04)	56	93	-39	(0.01-0.04)	137	47	+191	(0.01-0.04)	5.4	80.3	-93	(0.01-0.04)
•Soil 0-300cm	<0.5	<0.5			646	1007	-36	(0.01-0;04)	56	115	-51	(0.01-0.04)	137	202	-32	(0.01-0.04)	5.4	8.5	-36	(0.01-0.04)
•Soil 0-10cm	<0.5	<0.5			608	920	-34		54	106	-49		145	193	-25		5.5	8.3	-34	
•Soil 30cm	<0.5	<0.5			623	1040	-40		59	124	-52		118	196	-40		6.5	8.7	-25	
•Soil 100cm	<0.5	<0.5			608	1120	-46		56	123	-55		142	259	-45		4.4	8.9	-51	
•Soil 300cm	<0.5	<0.5			736	1180	-38		57	129	-56		117	218	-46		5.5	9.1	-40	

* Final/initial concentration at the test site

** TD-total digestible; AE-acid-extractable

CONTINUED

TABLE 19 (Concluded)

	Hg (TD)**				Mn (TD)				Ni (TD)				Pb (TD)				Zn (TD)			
Location/Depth	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Roswell																				
*Applied water	0.0006	<0.0005			<0.05	<0.05			<0.05	<0.05			<0.1	<0.1			0.08	<0.05		
*Soil 0-300cm	<0.5	<0.5			327	449	-27		12.1	13.6	-11		<7.5	<7.5			67.25	57.24	+17	
*Soil 0-10cm	<0.5	<0.5			355	410	-13	(≤0.05)	11	11.7	-6	(>0.05)	<10	<10			70	60	+16	(≤0.05)
*Soil 30cm	<0.5	<0.5			346	428	-19	(>0.05)	11.7	12.8	-9	(>0.05)	<10	<10			69	62	+11	(>0.05)
*Soil 100cm	<0.5	<0.5			266	441	-40	(>0.05)	12.9	16.5	-22	(>0.05)	<5	<5			64	61	+5	(>0.05)
*Soil 300cm	<0.5	<0.5			340	517	-34	(>0.05)	12.7	13.5	-6	(>0.05)	<5	<5			66	46	+43	(>0.05)
San Angelo									(AE)**				(AE)				(AE)			
*Applied water									0.08				0.07				0.19			
*Soil 0-40cm									2.29	2.24	+2		20	5.7	+251		17.3	0.8	+1960	
Tooele																				
*Applied water									<0.004	<0.002			0.002	0.002	0		0.015	0.013	+15	(>0.05)
*Soil 0-305cm									22.8	20.9	+9		22.8	21.8	+5		85.2	77.6	+10	
*Soil 0-11cm									21.1	22.2	+4		36.0	38.2	+6		110	105.0	+5	
*Soil 28-32cm									24.0	19.7	+22		17.5	14.7	+19		92.3	85.8	+8	
*Soil 95-105cm									26.4	15.8	+67		16.0	12.2	+31		77.5	58.6	+32	
*Soil 295-305cm									19.6	22.2	-12		12.1	10.6	+14		36.6	44.0	-17	

* Final/initial concentration at the test site

** TD-total digestible; AE-acid-extractable

TABLE 20 CONCENTRATIONS OF NONMETALLIC ELEMENTS IN SOIL (μg/g)

	As (TD)				B (WE)				Se (TD)			
Location/Depth	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)
Camarillo												
·Applied water	0.01	0.01	0	(>0.1)	0.85	0.23	+270	(0.01-0.04)	0.01	0.01	0	
·Soil * 1-300cm	2.0	3.3	-39	(0.01-0.04)	1.9	6.2	-69	(0.01-0.04)	15	<2.0	+650	(0.01-0.04)
·Soil 1-300cm	<2	5.7	-65	(0.01-0.04)	1.9	1.7	+12	(>0.1)	15	22	-32	(0.01-0.04)
·Soil 1-10cm	<2				2.1	1.7	+24		11.8	24	-51	
·Soil 30cm	<2	7.0			1.6	2.1	-24		8.9	17	-48	
·Soil 100cm	<2	5.1			2.1	1.7	+24		24	21	+14	
·Soil 300cm	<2	4.8			1.3	0.8	+63		14	17	-18	
Dickinson												
·Applied water	0.006	<0.005			0.92	0.25	+268		7	5	+40	
·Soil 0-300cm	6	5	+20		1.1	0.9	+22		<1	<1		
·Soil 0-10cm	7	4	+75	(≤0.05)	1.9	1.4	+38	(>0.05)	<1	<1		
·Soil 30cm	6	5	+20	(≤0.05)	1.4	0.9	+55	(≤0.05)	<1	<1		
·Soil 100cm	6	5	+20	(>0.05)	0.9	0.7	+29	(≤0.05)	<1	<1		
·Soil 300cm	6	6	0		0.7	0.6	+17	(>0.05)	<1	<1		
Mesa												
·Applied water	0.02	0.01	+100	(>0.1)	0.44	0.19	+130	(0.01-0.04)	0.01	0.01	0	
·Soil* 1-300cm	2.5	3.1	-19	(>0.1)	1.4	3.4	-59	(0.01-0.04)	6.0	<2	+200	(0.01-0.04)
·Soil 1-300cm	2.5	3.7	-33	(0.05-0.01)	1.4	1.3	+4	(>0.1)	6.0	13	-54	(0.01-0.04)
·Soil 1-10cm	2.5	1.4	+78		2.1	1.1	+91		3.3	15.9	-79	
·Soil 30cm	4.9	5.6	-13		1.0	0.7	+43		<2	17		
·Soil 100cm	<2.0	<2.0			0.8	0.6	+33		14	8.9	+57	
·Soil 300cm	<2.0	3.2			0.9	2.0	-55		5.2	12	-57	
Roswell												
·Applied water	<0.02	<0.02		(>0.05)	0.16	0.34	-53	(>0.05)	<0.01	<0.01		(>0.05)
·Soil 0-300cm	23.2	17.8	+30		1.02	0.69	+48		1.25	1.0	+25	
·Soil 0-10cm	21	17	+24	(>0.05)	1.15	0.65	+77	(≤0.05)	2	<1		
·Soil 30cm	22	18	+22	(>0.05)	1.14	0.75	+52	(>0.05)	1	<1		
·Soil 100cm	24	11	+118	(≤0.05)	0.92	0.68	+35	(>0.05)	1	<1		
·Soil 300cm	26	25	+4	(>0.05)	0.89	0.68	+31	(>0.05)	1	<1		

* Final/initial concentrations at the test site

TABLE 21 CONCENTRATIONS OF PATHOGENS AND INDICATOR ORGANISMS IN SOIL (No./g)

Location/Depth	Total Coliform Test	Total Coliform Cont	Fecal Coliform Test	Fecal Coliform Cont	Protozoa Test	Protozoa Cont	Nematodes Test	Nematodes Cont
Camarillo								
•Applied water	570	<0.02	2.2	<0.02				
•Soil* 1-300cm	$6x10^4$	$1.2x10^5$	$4.6x10^2$	<20	$4.5x10^2$	$3.3x10^2$	0.3	5.4
•Soil 1-300cm	$6x10^4$	$3.6x10^4$	$4.6x10^2$	$8.2x10^3$	$4.5x10^2$	$2.3x10^2$	0.3	1.3
•Soil 1-10cm	$12x10^4$	$8x10^4$	$1x10^3$		$5.8x10^2$	$4.9x10^2$	0.3	0.7
•Soil 30cm	$4.1x10^4$	$1.2x10^4$	55	<20	$1.5x10^2$	$1.2x10^2$	0	7.0
,Soil 100cm	$1.1x10^4$	$1.9x10^2$	<20	36	95	<2	0	1.0
•Soil 300cm	$5.9x10^3$	<20	<20	<20	<2	<2	0	0
Mesa								
•Applied water	$3.1x10^4$	113	$1x10^3$	10				
•Soil* 1-300cm	$2.0x10^4$	$5.0x10^5$	<20	<20	36	720	0.1	4.6
•Soil 1-300cm	$2.0x10^4$	$2.3x10^4$	<20	<20	36	35	0.1	0
•Soil 1-10cm	$43x10^3$	$33x10^3$	<20	<20	74	78	0.3	0
•Soil 30cm	$8.5x10^3$	$59x10^3$	<20	<20	21	<20	0	0
•Soil 100cm	$2.8x10^3$	$2.7x10^3$	<20	<20	<20	<20	0	0
•Soil 300cm	$0.7x10^3$	$1.3x10^3$	<20	<20	<20	<20	0	0

*Final/initial concentration at the test site

TABLE 21 CONCENTRATIONS OF PATHOGENS AND INDICATOR ORGANISMS IN SOIL (No./g)

Location/Depth	Total Coliform Test	 Cont	Fecal Coliform Test	 Cont	Protozoa Test	 Cont	Nematodes Test	 Cont
Camarillo								
•Applied water	570	<0.02	2.2	<0.02				
•Soil* 1-300cm	6x10^{4}	1.2x10^{5}	4.6x10^{2}	<20	4.5x10^{2}	3.3x10^{2}	0.3	5.4
•Soil 1-300cm	6x10^{4}	3.6x10^{4}	4.6x10^{2}	8.2x10^{3}	4.5x10^{2}	2.3x10^{2}	0.3	1.3
•Soil 1-10cm	12x10^{4}	8x10^{4}	1x10^{3}		5.8x10^{2}	4.9x10^{2}	0.3	0.7
•Soil 30cm	4.1x10^{4}	1.2x10^{4}	55	<20	1.5x10^{2}	1.2x10^{2}	0	7.0
•Soil 100cm	1.1x10^{4}	1.9x10^{2}	<20	36	95	<2	0	1.0
•Soil 300cm	5.9x10^{3}	<20	<20	<20	<2	<2	0	0
Mesa								
•Applied water	3.1x10^{4}	113	1x10^{3}	10				
•Soil* 1-300cm	2.0x10^{4}	5.0x10^{5}	<20	<20	36	720	0.1	4.6
•Soil 1-300cm	2.0x10^{4}	2.3x10^{4}	<20	<20	36	35	0.1	0
•Soil 1-10cm	43x10^{3}	33x10^{3}	<20	<20	74	78	0.3	0
•Soil 30cm	8.5x10^{3}	59x10^{3}	<20	<20	21	<20	0	0
•Soil 100cm	2.8x10^{3}	2.7x10^{3}	<20	<20	<20	<20	0	0
•Soil 300cm	0.7x10^{3}	1.3x10^{3}	<20	<20	<20	<20	0	0

*Final/initial concentration at the test site

TABLE 22 CONCENTRATIONS OF NUTRIENTS AND SULFUR IN VEGETATION (μg/g)

	N-Kjeldahl				$N-NO_3^-$				$N-NH_4^+$				P-total				S-total			
	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont ($PO_4^{\equiv}$)	% Δ	(SL)	Test	Cont ($SO_4^{=}$)	% Δ	(SL)
Camarillo																				
•Applied water													11.8	0.54	+2,260		194	227	-15	
•Tomato fruits													88	36	+144		24	113	-79	
•Broccoli heads													30	12	+150		66	57	-16	
Dickinson		(N-organic)																		
•Applied water	3.4	1.3	+162		1.5	4.0	-63		6.9	0.1	+6800		6.9	0.05	+13,700		--			
•	15	19	-21	(>0.05)	1014	649	+56	(>0.05)	380	221	+72	(>0.05)	2700	2700	0	(>0.05)	1074	1213	-11	
Mesa														($PO_4^{\equiv}$)				($SO_4^{=}$)		
•Applied water-test					1.8								9.0				67			
•Sorghum stalks					18								3,700				51			
•Barley seeds					--								--				--			
•Applied water-cont					2.7								0.5				54			
•Sudan grass					75								4,700				160			
•Cotton leaves and petioles					--								11				--			
Roswell		(N-organic)																		
•Applied water	41.3				1.6	1.2	+33	(>0.05)	23.3	0.1	+23,200	(≤0.05)	8.0	0.01	+79,900	(≤0.05)	--			
•Corn leaves	19,500	14, 00	+37	(>0.05)	700	915	-23	(>0.05)	647	335	+93	(>0.05)	3,400	2300	+48	(≤0.05)	552	844	-35	(0.05)
•Corn seeds	10,100				781				51				3500				370			
San Angelo		(N-Kjeldahl)												P-total						
•Applied water	35.2												21.6							
•Bermuda grass	21,600												2520							
•Coastal Bermuda	21,400												2510							
•Rescue grass	19,600												2770							
•Forage sorghum	20,200												3430							
Tooele																				
•Applied water	7.37	0.75	+883										9.55	0.062	+15,300					
•Bean seeds	48,100	48,400	-1	(>0.05)									6500	6400	+2	(>0.05)				
•Carrot roots	13,200	12,400	+6	(>0.05)									4100	2300	+78	(>0.05)				
•Corn seeds	25,200	35,200	-28	(≤0.01)									4800	4000	+20	(>0.05)				
•Lettuce	31,000	31,600	-2	(>0.05)									4500	3100	+45	(≤0.01)				
•Potato tubers	26,300	21,500	+22	(>0.05)									3300	2600	+27	(>0.05)				
•Tomato fruits	20,900	31,900	-34	(≤0.01)									5600	3300	+70	(≤0.01)				
•Wheat seeds	27,400	30,400	-10	(>0.05)									4500	4000	+13	(>0.05)				

TABLE 23 CONCENTRATIONS OF ALKALI AND ALKALINE EARTH METALS IN VEGETATION (µg/g)

	K				Na				Ba				Ca				Mg			
Location/Plant	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)	Test	Cont	% Δ	(SL)
Camarillo																				
·Applied water	16.9	4.6	+267		212	88.4	+140		0.08	0.17	-53		54.7	49.6	+10		33.7	40.1	-16	
·Tomato fruits	18,100	37,900	-52		6,100	900	+578		28	5	+460		23,700	825	+2773		14,500	3520	+312	
·Broccoli heads	76,500	24,800	+208		8,150	4,250	+92		29	47	-38		2,400	2,200	+9		10,400	10,800	-4	
Dickinson																				
·Applied water	24	12.4	+94		306	309	-1						55	55	0		15	30	-50	
·Brome grass	4300	5100	-16	(>0.05)	3100	1200	+158	(≤0.05)					3600	3300	+9	(>0.05)	1300	1300	0	
Mesa																				
·Applied water-test	18.1				215				0.16				46.8				41.8			
·Sorghum stalks	11,000				2500				<1				1800				2000			
·Barley seeds	6,200				150				4.9				100				2200			
·Applied water-cont	6.4				150				0.13				42.5				37.4			
·Sudan grass	20,500				11,000				10				2200				2000			
·Cotton leaves and petioles	22,000				4700				106				5000				19,000			
Roswell																				
·Applied water	14.7	6.1	+141	(≤0.05)	466	408	+14	(>0.05)					192	279	-31	(>0.05)	67	84	-20	(>0.05)
·Corn leaves	500	500	0		108	75	+44	(>0.05)					6960	9100	-24	(≤0.05)	4700	1200	+292	(>0.05)
·Corn seeds	500				54								100				<10,000			
Tooele																				
·Applied water	11.6	1.5	+673		128	19	+574						240	161	+49					
·Bean seeds	27,000	22,000	+23	(>0.05)	80.2	53.5	+50	(≤0.05)					2200	2000	+10	(>0.05)				
·Carrot roots	32,800	27,800	+18	(≤0.01)	4475	1847	+142	(≤0.05)					2900	2400	+21	(>0.05)				
·Corn seeds	14,000	17,300	-19	(>0.05)	21.5	28	-23	(>0.05)					500	700	-29	(>0.05)				
·Lettuce	65,000	66,300	-2	(>0.05)	7475	2400	+211	(≤0.01)					18,400	16,300	+13	(>0.05)				
·Potato tubers	18,400	20,000	-8	(>0.05)	307.5	73.2	+320	(≤0.01)					700	700	0					
·Tomato fruits	45,300	41,000	+10	(>0.05)	532	305	+74	(>0.05)					1700	1300	+31	(>0.05)				
·Wheat seeds	3600	3300	+9	(>0.05)	24	45.5	-47	(≤0.01)					900	900	0					

TABLE 24 CONCENTRATIONS OF HEAVY METALS (I) IN VEGETATION (μg/g)

	Cd				Cr				Cu				Fe			
Location/Plant	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)
Camarillo																
•Applied water	0.02	0.01	+100		0.02	0.03	-33		0.06	0.13	-54					
•Tomato fruits	<2	<2			2	3.9	-49		62	20	+210		280	490	-43	
•Broccoli heads	<2	<2			<2	<2			20	12	+67		405	344	+18	
Dickinson																
•Applied water	<0.01	<0.01			<0.02	<0.02			<0.02	<0.02						
•Bromegrass	<5	<5			5	2	+150	(≤0.05)	6.8	7.4	-8	(>0.05)				
Mesa																
•Applied water-test	0.02				0.04				0.08							
•Sorghum stalks	<1				<1				13				36			
•Barley seeds	<1								4.5				61			
•Applied water-cont	0.01				0.03				0.08							
•Sudan grass	1								21				655			
•Cotton leaves and petioles	4.7				1.7				21				1350			
Roswell																
•Applied water	<0.02	<0.02			0.02	0.01	+100	(>0.05)	0.07	0.05	+40	(>0.05)				
•Corn leaves	<2	<2			7	7	0	(>0.05)	19	12	+58	(>0.05)				
•Corn seeds	2				4				11							
San Angelo																
•Applied water	<0.004				0.124				0.3							
•Bermuda grass	0.33				0.83				6.8							
•Coastal berm. grass	0.37				1.18				7.8							
•Rescue grass	0.37				<0.5				6.9							
•Forage sorghum	0.23				≤0.7				7.9							
Tooele																
•Applied water									0.009	0.006	+50		0.064	0.127	-50	
•Bean seeds	10	10	0	(>0.05)					13.2	14	-6	(>0.05)	167.5	110	+52	(>0.05)
•Carrot roots	10	10	0	(>0.05)					8.75	11.5	-24	(≤0.01)	150	95	+58	(>0.05)
•Corn seeds	10	10	0	(>0.05)					8.75	9.5	-8	(≤0.05)	27.5	35	-21	(>0.05)
•Lettuce	10	10	0	(>0.05)					12.5	18.5	-32	(>0.05)	615	757	-19	(>0.05)
•Potato tubers	10	10	0	(>0.05)					11.75	12	-2	(>0.05)	72.5	67.5	+7	(>0.05)
•Tomato fruits	10	10	0	(>0.05)					23	24.5	-6	(>0.05)	135	115	+17	(>0.05)
•Wheat seeds	10	10	0	(>0.05)					8.0	8.0	0	(>0.05)	40.0	45.0	-11	(>0.05)

TABLE 25 CONCENTRATIONS OF HEAVY METALS (II) IN VEGETATION (μg/g)

	Mn				Mo				Ni				Pb				Zn			
Location/Plant	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)
Camarillo																				
•Applied water					0.11	0.10	+10		0.1	0.05	+100		0.05	0.08	-38		0.05	0.07	-29	
•Tomato fruits	4	11	-64		<10	<10			5	13	-62		27	19	+42		35	87	-60	
•Broccoli heads	75	84	-11		<25	<25			16	15	+7		11	16	-31		152	186	-18	
Dickinson																				
•Applied water	<0.05	0.23							<0.05	<0.05			<0.1	<0.1			<0.05	<0.05		
•Bromegrass	1.3	1.3	0	(>0.05)					<0.05	<0.05			<5	<5			37	22	+68	(≤0.05)
Mesa																				
•Applied water-test	--				0.1				--				--				--			
•Sorghum stalks	30				<10								<1				55			
•Barley seeds	28				<10								1				38			
•Applied water-cont	--				0.1															
•Sudan grass	131				<10								0.5				45			
•Cotton leaves and petioles	89				33								100				80			
Roswell																				
•Applied water	<0.05	<0.05							<0.05	<0.05			<0.1	<0.1			0.076	<0.05		
•Corn leaves	77	49	+57	(>0.05)					<5	<5			<10	<10			64	57	+12	(>0.05)
•Corn seeds	<10								<5				<10				26			
San Angelo																				
•Applied water									0.08								0.19			
•Bermuda grass									3.0								27			
•Coastal berm. grass									1.9								28			
•Rescue grass									1.3								21			
•Forage sorghum									2.4								47			
Tooele																				
•Applied water													0.002	0.002	0		0.015	0.015	0	
•Bean seeds													40	40	0		43.0	69.25	-38	(≤0.01)
•Carrot roots													40	40	0		19.5	33.25	-41	(≤0.01)
•Corn seeds													40	40	0		42.25	56.5	-25	(≤0.01)
•Lettuce													40	40	0		35.25	71.75	-51	(≤0.01)
•Potato tubers													40	40	0		24.25	38.75	-37	(≤0.01)
•Tomato fruits													40	40	0		28.5	40.25	-29	(≤0.05)
•Wheat seeds													40	40	0		53.75	74.5	-28	(≤0.01)

TABLE 26 CONCENTRATIONS OF NONMETALLIC ELEMENTS IN VEGETATION (μg/g)

	As				B				Se			
Location/Plant	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)	Test	Cont	Δ %	(SL)
Camarillo												
•Applied water	0.01	0.01	0		0.85	0.23	+270		0.01	0.01	0	
•Tomato fruit	2.1	1.0	+110		0.19	1.76	-89		0.8	0.1	+700	
•Broccoli head	4.5	8.0	-44		0.5	3.5	-86					
Dickinson												
•Applied water	0.006	<0.005			0.92	0.25	+268		0.007	0.005	+40	
•Bromegrass	<1	<1			19.6	14.1	+39	(>0.05)	<1	<1		
Mesa												
•Applied water-test					0.44							
•Sorghum stalks					<1							
•Barley seeds					--							
•Applied water-cont					0.19							
•Sudan grass					104							
Roswell												
•Applied water	<0.02	<0.02			0.164	0.34	-52	(>0.05)	<0.01	<0.01		
•Corn leaves	1	<1			28	32.6	-14	(>0.05)	<0.5	<0.5		
•Corn seeds	<1				10.5				<0.5			

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SECTION 7

DISCUSSION OF RESULTS AT EACH PROJECT LOCATION

This section discusses results of measurements made at each of the six project locations. In reading these discussions, one may wish to refer to the tabular results in Section 6. In general, specific tables are not cited in the discussions that follow since each table presents data for all project locations. Experimental or operating conditions that appear to affect test results are identified in the discussion of the project where the conditions occur.

CAMARILLO, CALIFORNIA

The principal differences between the effluent applied to the test site and the irrigation water applied to the control site were in the content of dissolved solids, nutrients, and coliforms. The concentrations of sodium, potassium, boron, chlorides, fluorides, nitrates, and phosphates as well as total and fecal coliforms were substantially higher in the effluent than in the irrigation water for the control site.

Leachate compositions were measured at the 50 cm and 100 cm depths with the aid of lysimeters. Potassium, chromium, and lead concentrations at the 50 cm depth were substantially higher at the test site, whereas sulfate and fluoride concentrations were higher at the control site. The difference was much more pronounced at the 100 cm depth, where nitrates, potassium, boron, and molybdenum concentrations were substantially higher at the test site, and sulfates, calcium, chromium, lead, and zinc were higher at the control site.

The concentrations of several constituents increased substantially with depth at both the test and control sites. These constituents included total dissolved solids, total nitrogen, nitrates, sodium, and magnesium. On the other hand, total organic carbon and phosphate concentrations increased with

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depth at the control site, but decreased at the test site. This anomaly may be accounted for by the different amounts of total organic carbon and phosphate supplied by plowing under of vegetation and by fertilization at the two sites.

Changes in groundwater concentrations were determined by comparing measurements of samples drawn from wells located upgradient and downgradient of the test site. The downgradient well exhibited somewhat higher concentrations of total dissolved solids, chlorides, total nitrogen and nitrates, and magnesium. This observation is consistent with the results reported above for the leachate.

Soil samples were collected at seven depths at the control and test sites both at the beginning and at the end of the one-year monitoring period. Statistical comparisons were then drawn between average pollutant concentrations at all depths, measured at the control and test sites (at both the beginning and at the end of the monitoring period), and between those measured at the beginning and at the end of the monitoring period (at both the control and test sites). The data presented here compare concentrations averaged over all depths at the test site at the beginning and end of the monitoring period, as well as concentration at each depth at the control and test sites.

Concentrations of nitrogen; phosphorus; fluoride; barium; boron; calcium; acid-extractable arsenic, chromium, and nickel; and total arsenic and lead decreased significantly at the test site during the one-year period of investigation. Concentrations of sodium, magnesium, acid-extractable copper and zinc, and total chromium and selenium, as well as the cation exchange capacity of the soil, exhibited significant increases. Total coliform count decreased with time, whereas the fecal coliform count increased.

Samples of five parts of three crop plants were collected on four different occasions and analyzed. At the test site, broccoli exhibited levels of phosphorus, potassium, calcium, and magnesium in excess of those expected. At the control site, spinach leaves showed excessive levels of calcium, magnesium, and copper. Over an extended period, the yield of tomatoes and broccoli on the test site was 12 percent and 4 percent higher, respectively, than on the control site.

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After more than 10 years of continuous land application of sewage effluent, no adverse health effects were detected among wastewater treatment works personnel, farm workers, or consumers. The project report attributed this absence of health effects to adequate pretreatment and avoidance of spray irrigation of the effluent [3].

DICKINSON, NORTH DAKOTA

The quality of the effluent varied widely because of its origin in several facultative lagoons where treatment processes are very difficult to control. The variations were particularly pronounced for suspended solids, BOD, COD, and nitrates. Values reported for the quality of river water used to irrigate the control site were based on only one sample. Therefore, caution should be exercised in drawing conclusions from comparisons of the quality of effluent applied to the test site and that of river water applied to the control site.

Groundwater samples were collected at various times during the one-year study period in a number of test wells in the alluvial and bedrock aquifers at both the test and control sites. Comparative values of 42 parameters for the test and control sites were reported first in each of the two aquifers, then at several points within the test site, and finally, as a function of time. Conductivity and concentrations of dissolved solids, COD, DOC, nitrate, soluble orthophosphate, chloride, sulfate, selenium, and certain heavy metals were markedly higher in the test site wells, whereas the concentration of lindane and the coliform count were substantially higher in control site wells.

Concentrations of 38 pollutants in the soil were measured and reported at four depths (0-10 cm, 30 cm, 100 cm, and 300 cm). Of these, 34 were significantly different at the 0-10 cm depth, 5 were significantly different for both the 0-10 cm and 30 cm depth, but none was significantly different at all four depths.

Samples of the bromegrass were collected at both the control and test sites on two occasions, five months apart, and 27 parameters were measured. Mean concentrations of sodium, chromium, manganese, and zinc were found to be significantly higher at the test site. The last three elements were also

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present in higher concentrations in the test site soil. Zinc levels were higher in the wastewater than in the irrigation water. There is no obvious explanation for the higher sodium content. All mean values were well within the normal range for grass crops.

MESA, ARIZONA

The principal differences between the qualities of the wastewater applied to the test site and the water used to irrigate the control site were in the content of dissolved solids and nutrients and in the coliform counts. The concentrations of sodium, potassium, boron, chloride, fluoride, total nitrogen, phosphate, arsenic, and cadmium were considerably higher in the test site wastewater, whereas the concentration of nitrates was higher at the control site.

Leachate compositions at the test and control sites were measured at the 50- and 100-cm depths. Differences at the 50-cm depth were not significant, but at 100 cm, the magnesium, nitrate, and zinc levels and the total coliform count were significantly lower at the test site. The significance of some results was vitiated by damage to several of the lysimeters.

Groundwater sampling wells were located upgradient, on-site, and downgradient of the test site, with the upgradient and downgradient wells serving as the control and test site wells, respectively. Samples were collected at the upper and lower level of each well. The principal changes in test-site groundwater quality were reflected in the increased concentrations of dissolved solids, boron, total nitrogen, and nitrate, but with a decrease in the total coliform count.

Soil samples were collected and analyzed for 43 parameters at seven depths and several points throughout the control and test sites, both at the beginning and at the end of the 14-month monitoring period. Results of the measurements were reported for each depth, each site, and each sampling time. Statistical comparisons were then drawn for average depths between the two sites, at the beginning and at the end of the monitoring period, and between the two sampling occasions, at the control and at the test site. Data presented here include values of selected parameters at four individual depths; at the end of the monitoring period; average values over all depths at the control and

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test sites, at the end of the monitoring period; and the average values over all depths at the test site, at the beginning and end of the monitoring period.

The concentrations of total nitrogen, acid-extractable phosphorus, water-extractable potassium, calcium, magnesium, and fluoride, and all total heavy metals were significantly higher at the control site, whereas concentrations of nitrates, phosphates, organic phosphorus, and a number of acid-extractable heavy metals were significantly higher at the test site. The concentrations of nearly all constituents decreased between the initial and final sampling time at both the control and test sites. The notable exceptions were the concentrations of organic phosphorus and phosphates, water-extractable sodium, potassium, and chlorides, as well as manganese and lead among the heavy metals. Nearly all concentrations at the test site decreased rapidly with increasing depth, with the exception of phosphorus, sodium, and some of the heavy metals.

Samples of Sudan grass and cotton leaves and petioles were collected at the control site, whereas samples of sorghum leaves and stalks, barley leaves and seeds, and corn leaves were collected at the test site on four occasions over a span of one year. Most of the 23 parameters measured were within the expected range for healthy crop tissues. At the test site, barley leaves were high in calcium and lead, whereas corn leaves were low in boron, magnesium, and phosphorus. At the control site, concentrations of iron and manganese were higher than expected in the Sudan grass whereas cotton leaves and petioles had higher than expected concentrations of most heavy metals measured. A direct comparison between plant uptake at the control and test sites was negated by the different types of crops planted.

ROSWELL, NEW MEXICO

The effluent from the Roswell wastewater treatment plant applied to the test site exhibited substantially higher concentrations of biochemical and chemical oxygen demand, organic compounds, all nutrients, and boron than the groundwater from the shallow aquifer used to irrigate the control site. The reverse was true of dissolved oxygen and dissolved solids. The exceptionally high COD and soluble organic concentrations were attributed to packing house

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wastes. The high levels of sulfate and other dissolved solids in the groundwater reflect the presence of soluble deposits in the municipal water supply aquifer.

Measurements of the surface runoff disclosed normally high levels of sediment and nutrients. Leachate measurements were not reported.

Groundwater was sampled in wells screened at different depths in all four seasons of the year. Comparative values averaged over the four seasons are reported for two depth ranges: less than 6 m and more than 6 m. All control-site wells were in the second group and all but one test-site well were in the first. Total alkalinity and nitrate were the only parameters with a significantly higher concentration in test-site groundwater, whereas chloride, sodium, ammonia, and selenium exhibited higher concentrations at the control site.

Nitrate level decreased with depth, but the other parameters were not significantly affected. More than a third of the parameters measured exhibited significant seasonal variations. These variations were attributed to fluctuations in groundwater movement and groundwater table, quality and quantity of wastewater, and amount of precipitation.

Soil samples were collected at six depths at the control and test sites and 38 constituent concentrations and other parameters were measured. Concentrations of nitrogen and phosphorus, as well as boron, chromium, copper, iron, lead, and zinc were significantly higher at the test site, whereas those of sulfur and calcium were significantly higher at the control site. The differences were generally attenuated with depth and only calcium and sulfur exhibited appreciable differences at the 300 cm depth. The values for selected parameters are compared here for the test and control sites at three depths and at the average depth.

Samples of corn leaves were collected at the control and test sites and samples of corn grains were collected at the test site alone. Among the 21 parameters measured, the phosphorus content of corn leaves was significantly higher at the test site, whereas the calcium content was significantly higher at the control site. Sulfur and calcium concentrations in the corn grains at the test site were below the normal range. Application of wastewater produced no detrimental effects on the corn crop.

SAN ANGELO, TEXAS

The experimental design of the San Angelo project differs from the other five projects (see Section 4). In contrast with the others, the San Angelo project did not provide a distinct control site. Water quality parameters were measured at the two lagoons that supplied the effluent applied to the test site, at 12 sampling wells on the test site varying in depth from 1.2 to 36.6 m, at 18 water supply wells outside the site varying in depth from 18 to 64 m, at three seepage creeks, and at two locations in the river, downstream and upstream of the test site.

The water quality parameter values reported here are for the combined effluents from two lagoons, for groundwater from shallow wells (<10 m) on the test site, for groundwater from deep wells (>10 m) on and off the test site (with the off-site wells serving as controls), and for river water downstream and upstream of the test site (with the latter serving as controls).

Samples were collected from three different types of soil at several depth ranges on both the control and test sites. Twelve chemical soil parameters were measured. Most of the results were reported in terms of mass per unit of land area (kg/ha), rather than mass per unit mass of soil (μg/g), which made them difficult to compare with results at other locations. Detailed results of extensive microbiological analyses were reported. The microbiological data have proved very useful in the analysis of conditions at the San Angelo site. However, they are not reported in the project document [7] in a form comparable to that of other projects. The data presented in this summary are those that could be useful in purposes of comparison; namely, the results of measurement of 11 chemical parameters at the control and test sites, averaged over all depths and all three soil types.

Multiple samples of four forage crops grown on the test site were collected and analyzed for only seven elements. None of the five heavy metals concentrations measured approached levels considered toxic.

TOOELE, UTAH

Evaluation of the effects of land treatment on groundwater quality, soil, and vegetation was complicated by several changes in effluent source and quality, and in method and rate of application of sewage treatment effluent.

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The values reported here are for effluent from the second reservoir (sampling station No. 4). The values are averaged over the two sampling times to provide for historical continuity in regard to the effects on soil and vegetation.

Effects on groundwater quality could not be evaluated because the water table was too low and the evaporation rate was higher than the combined rate of wastewater application and precipitation. Several attempts to measure leachate quality with the aid of lysimeters and porous tubes failed because of equipment breakdown and conflicting results.

Effects on soil were rather inconclusive not only because of the varied irrigation history but also as a result of different uses of the control and test sites. For example, any differences in nitrogen and phosphorus content due to variation in water quality would have been obscured by the fact that the control site was planted to alfalfa, whereas the test site was covered with grass, and both sites were grazed by cattle. Alfalfa is noted for fixing nitrogen from the air and consuming a large amount of phosphorus, whereas grass uses moderate amounts of both nutrients. Cattle manure is a rich source of both nutrients. The two sites did not exhibit major differences in soluble salts or metal content.

Soil samples were collected at up to 12 depth ranges from both the control and test sites on three occasions six months apart. Ten chemical parameters were measured. Four of these (total Kjeldahl nitrogen, NH_4^+, NO_3^-, and total phosphorus) were strongly affected by other uses of the land for growing alfalfa crops and grazing of cattle. Concentrations of chromium, nickel, and zinc were significantly higher at the test site. Results are reported in Tables 11 through 21 for all ten parameters averaged over the one-year monitoring period, at four depth ranges, and for both the control and test sites.

Multiple samples of 25 parts of 11 crop plants (alfalfa, beans, carrots, corn, lettuce, onions, peas, potatoes, radishes, tomatoes, and wheat) were collected from both the control and test sites and analyzed for four nutrients and six heavy metals. Nutrient levels were generally higher in plants grown on the test sites, whereas heavy metal concentrations were generally higher in plants at the control site. Both sites are located down wind of a large smelter. None of the heavy metal concentrations approached toxic levels.

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Results of extensive experiments on comparative growth rates and yields of plants grown on the test sites were reported as well. Data presented here are limited to mean concentrations of the four nutrients and six heavy metals in seven selected edible plant parts.

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SECTION 8

TRANSPORT AND FATE OF POLLUTANTS

This section traces the transport of individual pollutants contained in sewage effluent through the soil and groundwater, as well as their uptake by crop plants. The pollutants are classified into five categories: nitrogen and phosphorus, organics, solids, heavy metals, and indicator organisms. The reader may wish to refer to the tabulated data in Section 6. To facilitate such references, tables pertaining to a given pollutant category are identified in the following discussions.

NITROGEN AND PHOSPHORUS

Nitrogen and phosphorus compounds are major plant nutrients which assume a special importance in sewage treatment because they are present in large amounts, are difficult to remove by conventional treatment, and promote algae growth and eutrophication of lakes and streams. Slow-rate land treatment is uniquely suited to capture these pollutants and to utilize their nutritive value in growing commercial crops. Potassium, the third major plant nutrient, is discussed more conveniently in a later subsection, under "dissolved solids."

Nitrogen may be applied to the soil in the ionic form of ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), or organic nitrogen. It may also be reported as total nitrogen or as Kjeldahl nitrogen (total nitrogen less the nitrate). Ammonium, the most common form, and organic nitrogen are released by human fecal matter in sanitary sewage, by droppings of animals grazing on the site, by decomposition of algae in treatment and storage lagoons, and by decomposition crop debris on the sites. Ammonium may also be contributed by wastewater from commercial operations, such as packing plants and by leachate from fertilizers applied to the site. Nitrates are generated by biochemical oxidation of ammonium (nitrification) in the soil, whereas nitrites may be formed as an intermediate product of nitrification or through partial

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reduction of nitrates (denitrification). Nitrogen is removed from the soil through plant uptake of ammonium or nitrate ions and converted to protein; through volatilization as molecular nitrogen, nitrogen oxides, or ammonia; and through leaching to the groundwater in the form of nitrate.

The following observations are based on data presented in Tables 7, 15, and 22 of Section 6. Total nitrogen and ammonium nitrogen concentrations were much higher in the sewage effluent than in the irrigation water at the four reporting projects (Camarillo and Mesa for total N, Dickinson and Roswell for NH_4^+). Nitrate levels did not differ as markedly. Considerable equalization of concentrations occurred with depth, as the nitrogen compounds were taken up by plants. However, nitrate levels rose with depth, in part through nitrification and in part because of low affinity for soil particles. In fact, nitrate levels in groundwater in both the test and control sites consistently exceeded drinking water criteria in at least one location (Camarillo).

Concentrations in the soil as a function of depth were reported for total nitrogen and nitrate (Camarillo, Mesa, and Tooele), for organic and inorganic nitrogen (Dickinson and Roswell), and for ammonium (Tooele). The values at both the control and test sites generally decreased with depth, but the differences between the control and test sites did not exhibit any obvious trends.

The Tooele report compared the total nitrogen content at the control and test sites for a number of plant parts, but here again no trend was apparent. Limited measurements of total, organic, nitrate, and ammonium nitrogen in vegetation were reported for the Dickinson, Mesa, Roswell, and San Angelo projects.

Phosphorus in the soil occurs in the form of phosphate ($PO_4^{\equiv}$) and organic phosphorus. The sources of these compounds are similar to those cited for nitrogen compounds: human and animal fecal matter, decomposition of algal and crop debris, industrial processes, and application of fertilizers. Phosphates are also contributed by laundry wastewater. However, unlike nitrates, phosphates are readily retained by the soil through the formation of insoluble compounds with Al^{+++}, Ca^{++}, Fe^{+++}, $CO_3^{=}$, and OH^- ions. Once these ions have been used up, additional phosphate would penetrate deeper through the soil toward the groundwater.

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Phosphorus concentrations in leachate and groundwater as a function of depth were reported in the form of total phosphorus (San Angelo), soluble phosphorus (Dickinson), phosphate (Camarillo and Mesa), and soluble phosphate (Dickinson, Roswell, San Angelo). Both the phosphate concentrations and the differences in concentrations between the control and test sites decreased with depth.

In the soil, phosphorus concentration as a function of depth was reported as acid-extractable or total digestible phosphorus (all six locations), as available phosphorus (Dickinson and Roswell), and as water-extractable phosphate and organic phosphorus (Camarillo and Mesa). The levels of all these forms decreased rather consistently with depth for both the control and test site, though the decrease at the test sites appeared more rapid.

Phosphorus levels in vegetation were reported in forms of total phosphorus (Dickinson, Roswell, San Angelo, Tooele) and phosphate (Camarillo and Mesa). In those investigations that afforded a comparison between the same plant species at the control and test sites, the test site plants exhibited considerably higher phosphorus levels.

ORGANICS

Organic matter in sewage effluent is contributed by fecal and food wastes, by vegetation debris, and by industrial processes. Removal of organic matter by the soil takes place principally through biological digestion, as in conventional secondary treatment. Concentrations are usually indicated by measurement of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), but also of total and dissolved organic carbon (TOC and DOC). The quantity of organic matter found at some of the facilities was affected by changes in the algal growth in the effluent storage and treatment lagoons (Dickinson, San Angelo), by droppings from grazing animals, and by plowing under crops grown on the sites (Camarillo). Interpretation of the data to determine the effect of land treatment in removing organic matter in applied wastewater was greatly complicated by the other sources of these materials.

Limited BOD, COD and DOC measurements in groundwater were reported at Dickinson, Roswell and San Angelo, whereas the Camarillo and Mesa projects reported TOC values in the leachate and groundwater (see Table 8 of Section 6).

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In most cases, the levels appeared to decrease with depth, but the number and uniformity of results were insufficient to establish definite patterns.

SOLIDS

The term "total solids", encompasses suspended solids and dissolved solids. The first two terms are of small consequence in land treatment because suspended matter is typically filtered out by the first few centimeters of the soil bed. In fact, total and suspended solids were reported for the applied water only at the Dickinson project. "Dissolved solids" denotes the dissolved salts of alkali and alkaline earth metals and strong acids. They include such ions as Na^+, K^+, Mg^{++}, Ca^{++}, Ba^{++}, F^-, Cl^-, $CO_3^=$, HCO_3^-, $Si^=$, and $SO_4^=$. The B^{++} ion is also covered here as a matter of convenience. Dissolved solids were reported at the Camarillo, Dickinson, Mesa, and Roswell facilities. (See Tables 9, 10, 16, 17, 20, and 23 of Section 6).

Most dissolved solids occur naturally in the soil. Consequently, their concentrations in soil and groundwater frequently increase with depth, as they are leached out by the applied water and natural precipitation. In addition, sodium, boron, and sulfates are contributed to sewage effluent by laundry wastewater, and potassium may be introduced by certain fertilizers applied to the site. Chloride ions and, to a lesser degree, sodium ions leach more readily through the soil, whereas the other dissolved solids tend to be held more strongly by the soil particles.

Concentrations of both total and individual dissolved solids were generally higher in the sewage effluent than in the irrigation water. The notable exception was at the Roswell facility, which used groundwater for irrigation. Other exceptions were the concentrations of magnesium and sulfate at most of the four reporting facilities. This inequality persisted in water sampled at increasing depths, with the exception of deep groundwater samples. Furthermore, concentrations of total and individual dissolved solids in leachate and groundwater generally increased with depth at both the test and control sites. The key exception was potassium which was taken up by plants as an important nutrient in relatively large amounts.

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HEAVY METALS

Heavy metals are of special concern in land treatment because of their toxicity, their persistence in the environment, and the ability of living organisms to bioaccumulate them. These substances are taken up by crops grown on land treatment sites and ingested by humans or animals, or they may percolate to groundwater or surface water supplies. Small amounts of selected heavy metals such as copper and zinc are required for normal plant growth. Heavy metals are contributed primarily by wastewater from industrial processes such as metal finishing, but lead can be deposited by automobile exhaust emissions as well. None of the six facilities investigated exhibited excessive levels of heavy metals in the sewage effluent. Observations presented below are based on Tables 10, 11, 18, 19, 20 and 25 of Section 6.

Concentrations of cadmium, chromium, copper, lead, molybdenum, nickel, and zinc were reported as a function of depth for leachate and groundwater at the Camarillo and Mesa projects. More limited results were provided for most of these metals as well as for aluminum, cobalt, iron, manganese, and mercury at Dickinson, Roswell, and San Angelo. In general, metal levels were low at both the control and test sites and did not change appreciably with depth. In many cases the concentrations were higher at the control sites.

All the facilities with the exception of San Angelo reported on heavy metals levels in the soil as a function of depth. Here again, there was no appreciable change at different depths and in a number of cases, higher concentrations were noted at the control sites.

Heavy metal levels in various portions of crops grown on the control and test sites were reported for all six projects. At those projects that afforded a comparison between the same crops, all metals exhibited higher or equivalent concentrations in plants grown on the control site. None of the concentrations approached hazardous limits.

BACTERIOLOGICAL INDICATORS OF PATHOGENIC ORGANISMS

Pathogenic organisms represent another potentially important public health hazard and a cause for concern in land treatment of sewage effluent. The organisms can be inhaled as a component of an aerosol generated during spray

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irrigation or ingested during consumption of contaminated crops. Total and fecal coliform levels were measured in the leachate and groundwater at Camarillo, Dickinson, Mesa, and Roswell (Table 14). Total and fecal coliform as well as protozoa and nematodes were also measured in the soil as a function of depth at Camarillo and Mesa (Table 21).

Although indicator organisms levels were substantially higher in the sewage effluent than in the irrigation water, all but total coliforms were reduced to below detectable limits by passage through 300 cm of soil. Some elevated levels on crops were attributed to droppings from grazing animals. None of the workers or nearby residents at any of the investigated facilities exhibited any adverse health effects attributable to pathogens from land treatment.

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SECTION 9

COMPARISON OF SYSTEM DESIGN FACTORS WITH CRITERIA IN PROCESS DESIGN MANUAL

This section considers the possible changes in the design and predicted performance that might have resulted if the six slow-rate systems had been designed according to criteria in the Design Manual [1]. Of course, any comparison between the features of existing systems and the design criteria in the Design Manual is on an entirely hypothetical basis, since all of the systems were designed and in operation long before the Design Manual was published.

The Design Manual considers two principal limiting criteria for the design of slow-rate systems: hydraulic loading, and concentration of nitrogen in the leachate. The Manual identifies other criteria that can impose limits on system design, although these additional criteria apply only under certain circumstances. Examples of such criteria are the compatibility of constituents in the applied water with vegetation at the land application site, and the concentration of specified constituents in the leachate when groundwater is to be used for defined purposes such as drinking water supply.

The brief analyses that follow address the two principal criteria--hydraulic loading acceptability and leachate nitrogen concentration--for all projects where available data permit estimation of the required parameters. Certain other nonlimiting criteria are examined for some of the projects.

In reading the following analyses, one should bear in mind that the land application sites, with the possible exception of San Angelo, were not designed for the primary purpose of wastewater treatment, nor were they sized to accommodate a given wastewater loading. Rather, available municipal wastewater that had been treated at a primary or secondary (or in one case tertiary) facility was used as a source of water and nutrients for crop production. The wastewater was applied to the extent available at rates intended to improve crop productivity and not necessarily to optimize the reduction of pollutants in the leachate.

Following the practice employed in the Design Manual, the computations and tabular entries in the remainder of this section will generally be shown in English units, with SI conversions indicated as footnotes to the tables.

HYDRAULIC LOADING

The acceptable hydraulic loading of applied wastewater to slow-rate sites can be estimated from the water balance equation in the Design Manual (Equation 5-1):

$$L_w + Pr = ET + W_p + R$$

where: L_w = wastewater hydraulic loading rate, ft/yr (m/yr)

Pr = design precipitation rate, ft/yr (m/yr)

ET = evapotranspiration rate (or total consumption use of water by crop), ft/yr (m/yr)

W_p = water percolation rate, ft/yr (m/yr)

R = net runoff, ft/yr (m/yr)

For slow-rate systems, applied wastewater is assumed to percolate, so net runoff, R, is assumed to be neglible. Equating R=0 and rearranging yields:

$$L_w = (ET - Pr) + W_p$$

The percolation rate, W_p is a function of soil permeability or hydraulic conductivity. which is in turn related to soil texture.*

Given minimal information on soil characteristics at any location in the continental United States, a rough estimate of the hydraulic load (L_w) can be made from information in the Design Manual. The Manual suggests that estimates made in this manner are adequate only for preliminary planning. Such estimates of L_w have been made for each project location in this study and are compared with the actual wastewater loading applied.

NOTE ON COMPUTATIONS FOR TWO PROJECTS: At two locations--Camarillo and Mesa--measured values of hydraulic conductivity are reported at several depths down to 300 cm (9.8 ft), thus allowing a comparison with estimated values of the parameters based on soil texture. Reported values for the treated sites are given in Table 27.

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*In this section, the term "soil permeability" and "hydraulic conductivity" will be used interchangeably.

TABLE 27

HYDRAULIC CONDUCTIVITY OF SOILS AT
CAMARILLO AND MESA SITES

(Test Horizon)		Hydraulic Conductivity (Permeability)			
		Camarillo		Mesa	
cm	(in.)	cm/sec x 10^{-5}	(in/hr)	cm/sec x 10^{-4}	(in/hr)
1	(0.4)	1.96	(0.028)	4.30	(0.61)
3	(1.2)	0.91	(0.013)	5.77	(0.82)
10	(3.9)	10.8	(0.153)	5.17	(0.73)
30	(12.)	5.55	(0.0786)	4.90	(0.69)
100	(39.3)	2.9	(0.041)	7.33	(1.10)
200	(78.7)	0.44	(0.006)	32.7	(4.63)
300	(118.)	1.8	(0.026)	--	--

Source: [3] and [5]

The Design Manual suggests that the permeability of the most restrictive layer be used when estimating allowable hydraulic loading. At Camarillo, this value is 0.006 in./hr. and at Mesa, 0.61 in./hr. With field data as widely variable as those tabulated above, a preferred approach is to use the geometric mean of the measured values of permeability instead of any single measurement.* For Camarillo, the geometric mean is 0.031 in./hr (2.20 x 10^{-5} cm/sec) and for Mesa, 1.04 in./hr (7.36 x 10^{-4} cm/sec). In the tables that follow, two estimates of soil permeability will be used for each of these two locations: one based on soil texture class, the other the geometric mean of the measured values. The result will afford a comparison of estimated values of L_w based on soil classification and field data.

An example evaluation of estimated L_w based on the Design Manual procedure applied to the treated site at Roswell, New Mexico, is shown in Appendix B. Input data and calculated results for Roswell and the other five project locations are given in Table 28.

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*Carl G. Enfield, Robert S. Kerr, Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma. Personal Communication, November 6, 1980.

TABLE 28 ACCEPTABLE WASTEWATER HYDRAULIC LOADING (L_w) AS CALCULATED BY DESIGN MANUAL PROCEDURE

Location	Textural Classification Of Soil[d]	Permeability Range[a] Value Used For Computation	Upper Limit of Application Rate Excluding Evapotranspiration[b]	Growing Season	Allowable Percolation Rate (W_p)		Evapotranspiration Less Precipitation[c] (ET-Pr)	Wastewater Loading (L_w) Max. Allowable per Design Manual	Actual Measurements	
		In./hr	In./Week	Weeks	In./yr	Ft/yr	Ft/yr	Ft/yr	Ft/yr	In./wk
Camarillo	Loam (mocho loam with 25% clay)	Moderate to Moderately Slow (0.6)[a] (0.03)[e]	10 0.5	52	520 26	43.3 2.2	1.7	45.0 3.9	5.0	(1.2)
Dickinson	Fine sandy loam	Moderately Rapid (3.0)	45	30	1350	112.5	1.7	114.2	2.6	(0.6)
Mesa	•Vinity loam fine sand •Gilman loam	Moderate (2.0)[a] (1.04)[e]	38 20	52	1976 1040	165 87	4.6	170 92	16.5	(3.8)
Roswell	Silty clay, loam	Moderately Slow (0.4)	7.0	22	154	12.8	4.6	17.4	2.6	(0.6)
San Angelo	Silty clay Sand Gravel	Moderately Slow (0.4)	7.0	52	364	30.3	4.2	34.5	8.7	(2.0)
Tooele	Loam, Sandy loam Clay loam	Slow to Moderately Slow (0.4)	7.0	30	210	17.5	2.5	20.0	2.0	(0.5)

[a] Reference [1], (Design Manual), Tables 3-7 and 3-8
[b] Reference [1], Figure 3-3 (See also Figure B-1 in Appendix B of this report)
[c] Reference [1], Figure 3-2
[d] From individual reports on the six slow-rate projects (References [3] through [8])
[e] Computed from geometric mean of measured permeability values listed in NOTE in text (pages 63-64).

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Comparison Between Estimated and Measured Hydraulic Loading

Actual wastewater application rates and estimated acceptable rates obtained by means of the Design Manual procedure for all six slow-rate projects (together with data used in determining the estimated rates) are presented in Table 28. Actual application rates for each project are plotted against permeability rates for the six projects in Figure 2. The format of this figure, adapted from Figure 3-3 in the Design Manual, also shows the line indicating maximum acceptable wastewater application (also see Figure B-1 of Appendix B). It is clear from both Figure 2 and Table 28 that actual application rates at the sites fall below the acceptable maximum as estimated from the Design Manual in all cases, except the Camarillo estimate based on field measurements of soil permeability. For this one exception, actual rate exceeds the estimated acceptable rate by about a factor of two.

WATER PERCOLATION RATE: ESTIMATED AND MEASURED VALUES

An important step in estimating the acceptable hydraulic load, L_w, is the computation of the rate of water percolation (W_p) by the procedure in the Design Manual. The term W_p is also needed for estimating the concentrations of nitrogen compounds and other water pollutants in the water that percolates from the slow-rate treatment site to the groundwater, or drains to adjacent surface water.

As a check on the rough estimates produced by the Design Manual procedure W_p has been evaluated by using actual applied wastewater loadings (L_w actual), local precipitation data, and evaportranspiration data for specific crops and locations. This W_p, listed in Table 29, is presented to permit evaluating the nitrogen loading design with actual measured values of W_p rather than the maximum allowable values of W_p as calculated in Table 28.

NITROGEN CONCENTRATION IN PERCOLATE

The concentration of total nitrogen in the percolate from the treatment site is one of the limiting criteria in the Design Manual. The allowable concentration depends on the use classification of the groundwater. In this section, the most stringent use classification--drinking water source--will be assumed. The allowable concentration for this use is 10 mg/l.

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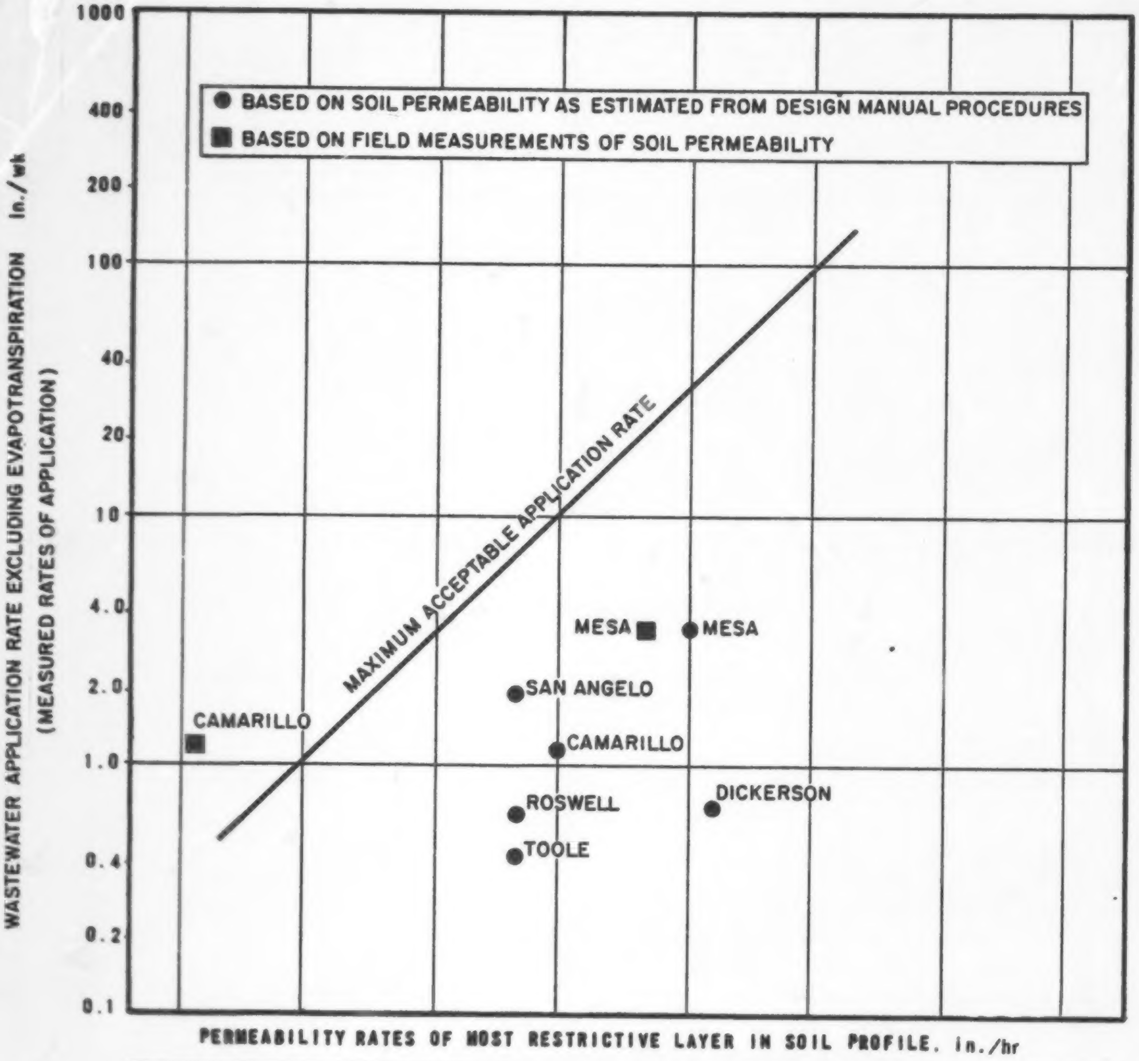

PERMEABILITY,* SOIL CONSERVATION SERVICE DESCRIPTIVE TERMS						
VERY SLOW	SLOW	MODERATELY SLOW	MODERATE	MODERATELY RAPID	RAPID	VERY RAPID
< 0.06	0.06–0.20	0.20–0.60	0.60–2.0	2.0–6.0	6.0–20.0	> 20.0

* MEASURED WITH CLEAR WATER

1 in./wk = 2.54 cm/wk

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Figure 2 Measured Values of Application Rate Versus Soil Permeability at Six Slow-Rate Project Sites

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TABLE 29 PERCOLATION RATES AS ESTIMATED FROM SITE DATA

PROJECT LOCATION AND CROP	Growing Season		Precipitation (Pr)			Evapo-transpiration (ET)		Wastewater Hydraulic Loading (L_w)		Runoff (R)	Net Evapo-transpiration (Pr - ET)	Percolation Rate (W_p)	
	Interval	No. of Months	Annual in.	During Growing Season in.	During Growing Season ft.	in/yr	ft/yr	in/yr	ft/yr		ft/yr	From Site Data ft/yr	(Allowable As Computed from Table 28) ft/yr
CAMARILLO		12	14.2[i]	14.2	1.2	40	3.3	61.4[k]	5.1	Net loading used in calculation	-2.1	3.0	43.3
Tomato	all year	6				20[j]							
broccoli		6				20							
DICKINSON		6	15[d]	12	1.0	33[e]	2.8	55	4.6	0	-2.1	2.5	112
Bromegrass	Apr - Sep												
MESA		12	7	7	0.6	66.3	5.5	198	16.5		-4.9	11.6	165
Barley	Dec - May					25.2							
Sorghum (grain)	Jul - Oct					21.5							
Corn (assume for silage)	Mar - Jul					19.6							
ROSWELL			12.6[b]	5.9[b]	0.5	24[a]	2.0	31[c]	2.6		-1.5	1.1	12.8
Corn (assume field corn)	Mar - Jul	5											
SAN ANGELO		12	21[g]	21	1.8	35[m]	3.0	104	8.7		-1.2	7.5	30.0
Oats (Acreage not specf'd)	Fall-Winter	4				16							
Sorghum (" ")	Spring-Summer	7				18							
Coastal Bermuda-346 ac.	Mar - Sep	7				40							
NK 37 -198 ac.	Warm season	8				40							
Ky 31 Fescue - 99 ac.	Nov - Jun	8				40							
Total -643 ac.													
TOOELE		6	17	12	1.0	40	3.3	24[f]	2.0		-2.3	-0.3	17.5
Grasses, Alfalfa mixed	May - Oct					40[f]							

[a] The Water Encyclopedia, Table 2-51, p. 96
[b] Reference [6], Table 5, p. 24
[c] Ibid, Figure 6, p. 21
[d] Reference [4], pages 25-27
[e] Water Encyclopedia, Table 2-51, p. 96
[f] Reference [8], p. 45
[g] Reference [7], p. 24
[h] Water Encyclopedia, p. 96
[i] Climate of the States (Vol. 2)
[j] Reference [3], p. 89
[k] Ibid., p. 90
[m] Average of ET rates itemized below, weighted by acreage for each.
[n] Reference [5], p. 92

Estimation Procedure

The nitrogen concentration in the percolate, C_{Np}, may be estimated from the annual nitrogen balance equation (Equation 5-2 from the Design Manual):

$$L_{Nw} = U_N + D + 2.7\ W_p\ C_{Np}$$

where: L_{Nw} = nitrogen loading from applied wastewater, lb/acre-yr

U_N = crop uptake of nitrogen, lb/acre-yr

D = rate of denitrification = 0.2 L_{Nw} (assuming denitrification to be 20% of applied nitrogen)

W_p = rate of water percolation, ft/yr

C_{Np} = concentration of nitrogen in percolate, mg/l

The factor 2.7 is to adjust units.

From the above equation,

$$C_{Np} = \frac{L_{Nw} - U_N - D}{2.7\ W_p} = \frac{0.8\ L_{Nw} - U_N}{2.7\ W_p}$$

If nitrogen is added from fertilizer, the equation must be modified to relfect this additional loading, L_{Nf}:

$$C_{Np} = \frac{0.8\left(L_{Nw} + L_{Nf}\right) - U_N}{2.7\ W_p}$$

Nitrogen loading from wastewater is evaluated by the equation

$$L_{Nw} = 2.7\left(C_{Nw}\right)\left(L_w\right)$$

where: C_{Nw} is the concentration of total nitrogen in the wastewater, mg/l

L_w is the rate of wastewater application, ft/yr.

The procedure for computing percolate nitrogen concentration is illustrated in Appendix B for the Roswell project. Input data for all projects are presented in Table 30, and computed values of C_{Np} are compared with measured values for each project.

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TABLE 30 NITROGEN CONCENTRATION IN PERCOLATE

	Conc. of Total N in Wastewater (C_{Nw}) mg/l	Hydraulic Loading of Wastewater Actual (L_w) ft/yr	Crop Uptake of Nitrogen (U_N) lb/a-yr	Percolation Rate (from Site Data) (W_p) ft/yr	Nitrogen Loading from Wastewater ($2.7\ C_{Nw}L_w$) = (L_{Nw}) lb/a-yr	Net Nitrogen Loading $0.8L_{Nw} - U_N$ lb/a-yr	Conc. of in Percolate $C_{Np} = \frac{0.8L_{Nw}-U_N}{2.7W_p}$ mg/l	Nitrogen Applied as Fertilizer (L_{Nf}) lb/a-yr	Total Nitrogen Loading $L_{NT} = 0.8\ (L_{Nf} + L_{Nw}) - U_N$ lb/a-yr	Nitrogen Concentrations in Percolate, C_{Np}	
										Calculated Values $L_{NT}/2.7W_p$ mg/l	Measured Values at Sites mg/l
CAMARILLO	35	5.1	194^{a}	2.9	207	(-78)	Calculated Negative	242^{b}	165	21.1	64
Tomatoes Broccoli			Combined Uptake								
DICKINSON	11.8^{c} (Total organic-N + NH_3-N + NO_3-N)	4.6	160	0.8	167	(-13)	Calculated Negative	14^{d}	(-18)	Calculated Negative	2.4^{e}
MESA	24.9^{f} (Total N)	16.5	262^{g}	11.6	1109	625	20	None	--	20	46.4^{f}
Barley Sorghum Corn			Combined Uptake								
ROSWELL	42.9^{h}	2.6	160^{i}	1.1	~300	80	26.9	None	--	26.9	13.7 (<6m) 6.4 (>6m)
Corn											
SAN ANGELO	34.5^{j} avg.	8.7	550^{k}	7.5	832	115	5.7	62.5^{n} (Does not include manure from live-stock grazing)	165	8.1	5.8 (Groundwater) 6.4 (River)
TOOELE											
Grasses^{l} (50%) Alfalfa (50%)	13.2^{m}	2.0	310 avg.	-0.3	71.3	(-253)	Calculated Negative	51^{e}	- 202	--	--

References on following page.

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TABLE 30 (Concluded)

REFERENCES:

a) Reference [3], Table 34
b) Ibid, Table G-6
c) Reference [4], Table 7
d) Ibid, Page 27
e) Ibid, Table 9
f) Reference [5], Table 9
g) Ibid, Table 35
h) Reference [6], Table 11
(cf. Table 7)
i) Design Manual, Table 5-32
j) Reference [7], Tables 12 and 13
k) Reference [1], Table 5-32
m) Reference [8], Page 47 (TKN + NO_3-N, averaged for 1976-77)
n) Reference [9], Table 1
p) Reference [8], Page
q) Estimate of Crop Uptake of N at San Angelo:

$$\left.\begin{matrix}\text{Oats}\\ \text{Sorghum}\end{matrix}\right\} \quad 300 \text{ lb/a-yr (estimated)} \times \tfrac{1}{2} \text{ year} = 150$$

Coastal Bermuda	346 a	475^k	x	346	=	164,350
NK-37	198 a	350	x	198	=	69,300
Ky-31	99 a	213	x	99	=	21,300
						254,900/640 = $\frac{398}{548}$ ≅ 550 lb/a-yr

r) Estimate of Crop Uptake of N at Tooele:

$$\begin{matrix}\text{Grasses}\\ \text{Alfalfa}\end{matrix} \begin{pmatrix}50\%\\ 50\%\end{pmatrix} \left.\begin{Bmatrix}280 \text{ (grass)}\\ 340\end{Bmatrix}\right. = 310 \text{ lb/a-yr}$$

s) No fertilizer except manure from grazing livestock

$$\left.\begin{matrix}\sim 5000 \text{ sheep-days/yr} \times 9 \text{ lb N/yr} = 123 \text{ lb/yr}\\ \sim 8500 \text{ cattle-days/yr } 61 \text{ lb N/yr}^{n} = 1420\end{matrix}\right\}$$

t) Reference [7], page 74

TABLE 30 (Concluded)

REFERENCES:

a) Reference [3], Table 34
b) Ibid, Table G-6
c) Reference [4], Table 7
d) Ibid, Page 27
e) Ibid, Table 9
f) Reference [5], Table 9
g) Ibid, Table 35
h) Reference [6], Table 11
(cf. Table 7)
i) Design Manual, Table 5-32
j) Reference [7], Tables 12 and 13
k) Reference [1], Table 5-32
m) Reference [8], Page 47 (TKN + NO_3-N, averaged for 1976-77)
n) Reference [9], Table 1
p) Reference [8], Page
q) Estimate of Crop Uptake of N at San Angelo:

$$\left(\begin{matrix}\text{Oats}\\ \text{Sorghum}\end{matrix}\right\} \quad 300 \text{ lb/a-yr (estimated)} \times \tfrac{1}{2} \text{ year} = 150$$

```
Coastal Bermuda 346 a    475^k x 346 = 164,350
NK-37           198 a    350   x 198 =  69,300
Ky-31            99 a    213   x  99 =  21,300
                                     254,900/640 = 398/548 ≅ 550 lb/a-yr
```

r) Estimate of Crop Uptake of N at Tooele:

$$\begin{matrix}\text{Grasses}\\ \text{Alfalfa}\end{matrix} \begin{pmatrix}50\%\\ 50\%\end{pmatrix} \left\{\begin{matrix}280 \text{ (grass)}\\ 340\end{matrix}\right\} = 310 \text{ lb/a-yr}$$

s) No fertilizer except manure from grazing livestock
$$\left.\begin{matrix}\sim 5000 \text{ sheep-days/yr} \times 9 \text{ lb N/yr} = 123 \text{ lb/yr}\\ \sim 8500 \text{ cattle-days/yr } 61 \text{ lb N/yr}^n = 1420\end{matrix}\right\}$$

t) Reference [7], page 74

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Comparison of Estimated and Measured Values of Nitrogen in Percolate

As indicated by the Roswell example and the other projects listed in Table 30, there is relatively low correlation between the observed average values of percolate nitrogen concentration and the estimated values obtained from the procedures outlined above. The differences between observed and estimated values of this parameter suggest that the estimating procedures should be carefully examined.

COMPARISON OF LEACHATE PARAMETERS WITH DRINKING WATER STANDARDS

Although the Design Manual does not recommend that drinking water standards other than nitrate nitrogen concentration be considered as limiting criteria in the design of slow-rate land treatment systems, it is nevertheless interesting to compare the allowable levels of criteria parameters specified in EPA standards for drinking water supply with the measured concentration of the same substances in the groundwater at test sites. An overall summary comparison is shown in Table 31. The project groundwater data used in this comparison are the average concentrations summarized in Tables 7 through 26 of this report. These do not indicate variations with time or sampling location for any given project. More detailed presentations of pollutant concentrations in groundwater for each project may be found in References [3] - [8].

Data in Table 31 indicate that the concentrations of most drinking water criteria parameters are well within the acceptable maximum levels at most of the treated sites. However, the measured levels of nitrate-N, selenium, and total coliform equal or exceed the criteria levels at all sites reported. This observation does not, in itself, indicate that the higher-than-acceptable levels of these constituents are a result of land treatment, since the concentrations of some of these substances in groundwater at the control sites also exceed criteria levels for drinking water supply (cf. Tables 7 - 14).

It is noted that Table 31 lists only chemical, bacteriological, and pesticide parameters included in the interim drinking water standards of December 1975. Radionuclides (added in 1976), trihalomethanes (added in 1979), and turbidity are not included. The table does not list data for the Tooele project, since no groundwater was detected and hence no samples were taken.

TABLE 31 COMPARISON OF DRINKING WATER CRITERIA AND GROUNDWATER PARAMETERS AT TREATMENT SITES

Constituent	Drinking Water Standard[a] (Value)	Concentrations in Groundwater or Leachate at Treated Sites[b]					
Chemical (mg/1)		Camarillo	Dickinson	Mesa	Roswell	San Angelo	Tooele
Arsenic	0.05	0.01	0.014	0.02	<0.02	--	No Measurements
Barium	1.0	0.16	--	0.19	--	--	
Cadmium	0.01	0.02	<0.01	0.01	<0.02	<0.004	
Chromium	0.05	0.03	<0.02	0.03	<0.02	<0.005	
Fluoride	1.4 to 2.4*	1.1	--	0.79	--	--	
Lead	0.05	0.12	<0.1	0.19	<0.10	<0.05	
Mercury	0.002	--	<0.0001	--	<0.0005	--	
Nitrates (as N)	10.	52.8	1.8	9.9	6.5	15.7	
Selenium	0.01	0.01	0.02	0.01	0.03	--	
Silver	0.05	--	--	--	--	--	
Bacteriological (No./100 ml)							
Total coliform	1	410	59	9	TNTC**	1000 to 100,000	
Pesticides (mg/1)[c]							
Endrin	0.0002	--	***	--	***	--	
Lindane	0.004	--	∿0.00001[c]	--	0.00007[d]	--	
Methoxychlor	0.01	--	***	--	***	--	
Toxaphene	0.005	--	***	--	***	--	
2, 4-D	0.01	--	∿0.000008	--	0.00001	--	
2, 4, 5-TP	0.01	--	∿0.00003	--	0.00003	--	

-- = Not reported
* = Dependent on temperature; higher limits for lower temperatures
** = TNTC - Too numerous to count
*** = Not observed at detectable limit

[a] Reference [1]
[b] Tables [7 thru 14]
[c] Reference [4]
[d] Reference [6]

Some of the data for the San Angelo project are for groundwater at the site, others are for seepage creeks. The location of these measurements within the San Angelo site can be readily determined by comparing Table 31 with Tables 7 through 26.

OBSERVATIONS BASED ON COMPARISON OF FIELD MEASUREMENTS WITH ESTIMATES FROM DESIGN MANUAL PROCEDURES

In any comparison involving field measurement data on hydraulic loading or nitrogen loading, it should be recognized that the data available from the source references are subject to errors of estimation ordinarily associated with these types of measurements. With the comments on field measurement data presented in Section 5 in mind, we have compiled the following observations on the comparison between estimated and observed values of hydraulic loading and nitrogen loading.

Hydraulic Loading

Estimates of maximum allowable hydraulic loading based on procedures outlined in the Design Manual appear to provide appropriate values for the maximum loadings at the six sites. Actual loadings at all sites fell below the allowable values estimated by the Design Manual method, although in one case (Camarillo) the actual loading exceeded the allowable value calculated by a modification of the Design Manual procedure.

Nitrogen Loading

Estimates of total nitrogen concentration in the leachate or percolate based on procedures in the Design Manual deviated substantially from measured values of this parameter at all five project locations where this parameter was measured. The differences between estimated and measured values could be the result of a number of factors. We shall not attempt to speculate about specific reasons for these differences, but will point out a few factors that might have been involved.

First, the Design Manual procedure for estimating leachate nitrogen concentration involves a straightforward nitrogen balance based on equilibrium (steady-state) conditions. These conditions do not account for the retention of nitrogen (or nitrogen compounds) in the soil, the release of nitrogen from the soil, or the time lag between application of nitrogen and its appearance in the leachate. Thus the assumed equilibrium conditions may not correspond to actual conditions in the field, which in the short-term may change rapidly.

Second, data on the crop uptake of nitrogen was not available from the source references for each project location. In some cases, values of this parameter were estimated from data on other locations with different growing conditions, thereby introducing some degree of inaccuracy. Also, the assumption that 20 percent of applied nitrogen is accounted for by denitrification processes in the soil may not be strictly applicable in all circumstances.

Third, the Design Manual procedure for nitrogen in the percolate does not account for the nitrogen content of fertilizer other than the nutrient content of wastewater. However, even when nitrogen applied in fertilizer is considered (as in Table 30), large disparities between measured and estimated values of nitrogen in the percolate still remain.

Fourth, field data on nitrogen loading from applied water and nitrogen concentrations in the percolate are subject to error of measurement and estimation, and cannot be expected to precisely match preliminary estimates obtained from the Design Manual calculations.

Consideration of these factors leads to the conclusion that the assumptions underlying the Design Manual procedure for estimating percolate nitrogen concentration, and their implications for accuracy of the resulting estimates, should be discussed more thoroughly in any subsequent edition of the Design Manual. A recommendation to this effect is made in Section 3 of this report.

SECTION 10

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APPENDIX A

SITE SELECTION CRITERIA

Many factors ranging from cropping history to cooperativeness of local officials were weighed in decisions leading to the selection of each site. The specific conditions listed below were considered in site selection.

- Uniform permeability of soils--

  Each test site and control site should have the same type of soil with the same general, reasonably uniform permeability. The soil should not contain any well-defined channels through which the applied water could escape without contact with the chemicals in the soil mass.

- Same site--

  The same site should have been used for a long time. If wastewater had been applied to first one and then another site over the period of operation the concept of the long-term effect would not be applicable.

- Depth to groundwater--

  The depth to groundwater should be sufficient to permit good crop production, yet shallow enough to allow economical sampling of the water. The thickness of the aquifer should be adequate to permit a large body of soil to react with the applied wastewater.

- Accounting for chemical elements--

  Sufficient data should be available to estimate the total mass of chemical elements applied with the wastewater, the amount percolated through the soil, the amount taken off in the crops, and the amount that has remained in the soil.

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- **Constant quality--**

  No substantial change should have occurred in the chemical quality of the applied wastewater over the period being studied.

- **Extraneous sources--**

  If chemicals other than those in the wastewater have been applied on the study sites, such an application can introduce uncertainties into the operation that would make the analyses difficult. Other factors being equal, sites at which other sources of chemicals have been applied should be avoided.

In addition, the following general criteria were considered:

- Flow rates should be at least 4.38 l/s (0.1 Mgal/d).
- Historical records should be available for at least 10 years.
- The applied wastewater should be effluent from either primary or secondary treatment.
- A good control site should be within a reasonable distance and have the same general type of soil and hydrogeological conditions.

The above listed conditions and criteria are cited, with minor modifications, in several of the six project reports [3 - 8]. The specific wording used above is adapted from Reference [4].

APPENDIX B

EXAMPLE CALCULATIONS OF WASTEWATER HYDRAULIC LOADING AND PERCOLATE NITROGEN CONCENTRATIONS

WASTEWATER HYDRAULIC LOADING

The soil texture at the Roswell test site is characterized generally as silty clay loam, and the hydraulic conductivity (permeability) as moderately slow ([6] , pages 22-23). According to Table 3-7 of the Design Manual, this permeability classification is considered to have a permeability rate of 0.2 to 0.6 in/hr.* An intermediate value of 0.4 in/hr will be used in this calculation.

The value of soil permeability thus determined is used as a basis for estimating acceptable wastewater application rate by means of Figure 3-3 in the Design Manual, reproduced here as Figure B-1. This graph indicates that the maximum acceptable rate of wastewater application (excluding evapotranspiration) is about 7.0 in/week as read from the straight line that forms the upper boundary of the shaded area. The growing season for corn at the Roswell site is March through July [6], which is estimated to include a 22 week period during which wastewater is applied to the land. The rate of 7 inches per week for a 22 week season per year corresponds to an annual loading of:

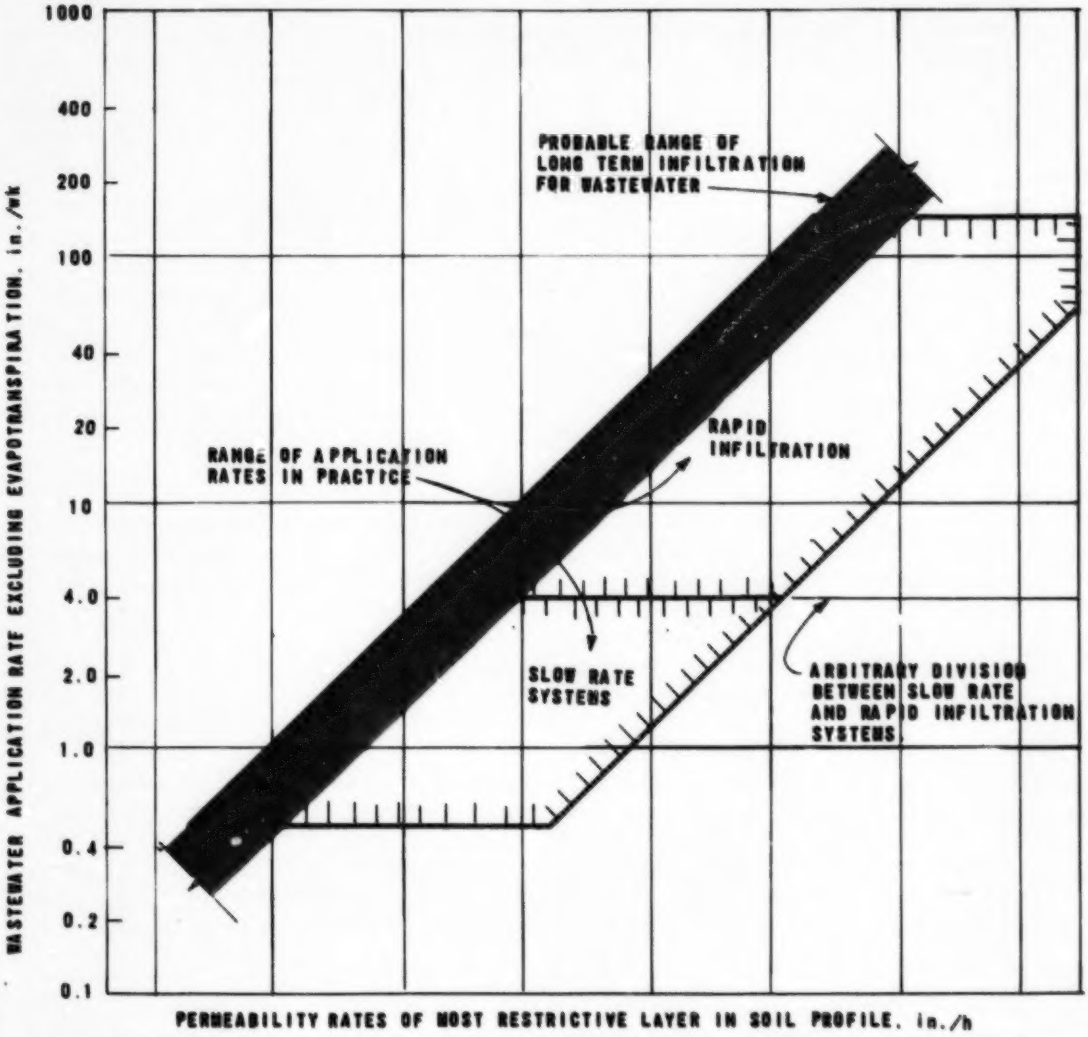
$$(7 \text{ in/wk}) (22 \text{ wk/yr}) (1 \text{ ft}/12 \text{ in}) = 12.8 \text{ ft/yr}$$

This rate, which is numerically equal to the percolation rate, W_p, in the water balance equation,** must be adjusted for evapotranspiration and precipitation to determine the acceptable rate of wastewater application. Figure 3-2 of the Design Manual indicates that Roswell is located in an area where

---

*This general textural classification, permeability class, and permeability rate are borne out in the more detailed description of the soil profile of the Roswell site given in Reference [6]. Although one layer (at 46.5 to 62.2 inches depth) is classified as "very slow", the permeability rate is given as "less than 0.6 in/hr." For the present example, this value is assumed to be consistent with the value of 0.4 in/hr used in the calculation.

**Given in Section 9 of this report.



PERMEABILITY* SOIL CONSERVATION SERVICE DESCRIPTIVE TERMS						
VERY SLOW	SLOW	MODERATELY SLOW	MODERATE	MODERATELY RAPID	RAPID	VERY RAPID
< 0.06	0.06-0.20	0.20-0.60	0.60-2.0	2.0-6.0	6.0-20.0	> 20.0

* MEASURED WITH CLEAR WATER

SOURCE: Reference 1

1 in./wk = 2.54 cm/wk

Figure B-1 Soil Permeability Versus Ranges of Application Rates For Slow-Rate and Rapid Infiltration Treatment annual evapotranspiration (ET) exceeds precipitation (Pr) by about 4.6 ft/yr. This quantity, which is equal to the term (ET-Pr) in the water balance equation, is added to the annual allowable percolation rate of 12.8 ft/yr, as estimated above from soil permeability, to yield net acceptable wastewater loading:

$$L_w = 4.6 \text{ ft/yr} + 12.8 \text{ ft/yr} = 17.4 \text{ ft/yr}$$

This estimated rate is well above the actual application rate of 2.6 ft/yr reported in [6], suggesting that the actual rate could be increased by a factor of 5 without exceeding the hydraulic loading limitation imposed by soil permeability.

NITROGEN CONCENTRATION IN PERCOLATE AT ROSWELL PROJECT

The average concentration of nitrogen in the applied water, C_{Nw}, at the Roswell test site was 66.2 mg/l (reported as total organic N, ammonium-N, and nitrate-N in [6], Table 11). The wastewater hydraulic loading is 2.6 ft/yr. The nitrogen loading from wastewater is calculated as:

$$\begin{aligned} L_{Nw} &= 2.7\ C_{Nw}\ L_w \\ &= (2.7)(42.9)(2.6) = 301.0 \cong 300 \text{ lb/a-yr} \end{aligned}$$

The Roswell test site is planted to corn, which has an annual nitrogen uptake, U_N, of 155 to 172 lb/a-yr [1]. An intermediate value of 160 lb/a-yr is assumed here.

Since no fertilizer was applied at Roswell, the term L_{Nf} in the equation for C_{Np} (given in Section 9) is zero. C_{Np} can now be evaluated from information developed above by means of the equation:

$$\begin{aligned} C_{Np} &= \frac{0.8\left(L_{Nw} - L_{Nf}\right) - U_N}{2.7\ W_p} \\ &= \frac{0.8\ (300 + 0) - 160}{2.7\ W_p} \end{aligned}$$

Two values of W_p are available to complete the computation. If the value of 12.8 ft/yr, from the Design Manual procedure based on soil permeability (see Table 28), is used, the resulting value of C_{Np} is 2.3 mg/l. However, if the value of W_p = 1.1 ft/yr, based on local meterological data and actual wastewater

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application rates (see Table 29), is used, the calculated value of C_{Np} is 26.9 mg/l. When these two estimates are compared with the measured concentrations of nitrogen in the percolate at two depths[6], (Table 23),

Average at depths <6m = 13.7 mg/l
Average at depths >6m - 7.3 mg/l

the magnitude of the difference between estimated and observed concentrations is apparent.

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